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Project Management Branch Section B

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YUCCA MOUNTAIN - REQUEST FOR ADDITIONAL INFORMATION - SAFETY EVALUATION REPORT, VOLUME 3 - POSTCLOSURE CHAPTER 2.2.1.3.6 - FLOW PATHS IN THE UNSATURATED ZONE, SET 1 - (DEPARTMENT OF ENERGY'S SAFETY ANALYSIS REPORT SECTIONS 2.3.2 AND 2.3.3)

Reference: Ltr, Sulima to Williams, dtd 04/29/09, "Yucca Mountain – Request for Additional Information – Safety Evaluation Report, Volume 3 – Postclosure Chapter 2.2.1.3.6 – Flow Paths in the Unsaturated Zone, Set 1 – (Department of Energy's Safety Analysis Report Sections 2.3.2 and 2.3.3)"

The purpose of this letter is to transmit the U.S. Department of Energy's (DOE) responses to the remaining two (2) of the nine (9) Requests for Additional Information (RAI) identified in the above-referenced letter regarding DOE's License Application Sections 2.3.2 and 2.3.3. Each RAI response is provided as a separate enclosure. Please note that DOE submitted seven (7) responses to RAIs from this set on June 1, 2009, and resubmitted a revised response to RAI Number 5 on June 10, 2009.

Enclosure 3 contains a PDF of an Excel spreadsheet with the data requested in RAI Number 9. As requested by NRC, the Excel spreadsheet in its native format has been provided separately and made available to the public.

All DOE references cited in the RAI responses have previously been provided with the License Application (LA), the LA update, or as part of previous RAI responses. The reference provided with a previous RAI response is identified within the enclosed response reference section.

There are no commitments in the enclosed RAI responses. If you have any questions regarding this letter, please contact me at (202) 586-9620, or by email to jeff.williams@rw.doe.gov.

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Licensing Interactions Branch
Regulatory Affairs Division
Office of Technical Management

OTM: CJM-0853



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Enclosures (3):

1. Response to RAI Volume 3, Chapter 2.2.1.3.6, Set 1, Number 1
2. Response to RAI Volume 3, Chapter 2.2.1.3.6, Set 1, Number 9
3. PDF file *Tables_2-9.pdf* (this is a PDF of Excel file *Tables_2-9.xls* referred to in response to RAI Number 9)

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EIE Document Components:

001_NRC_Tran_Ltr_3.2.2.1.3.6_Set_1_No_3.pdf	
002_Encls_RAI_1_and_9_3.2.2.1.3.6_Set_1.pdf	26,780 KB
003_Tables_2-9.pdf	670 KB

RAI Volume 3, Chapter 2.2.1.3.6, First Set, Number 1:

Explain how the calibrated and uncalibrated properties used in unsaturated flow models are adequately supported by observations.

To support the explanation, provide a summary table describing the hydrologic and pneumatic observations used to calibrate the three-dimensional unsaturated zone site-scale flow model. The description should include information for each borehole, including as appropriate: (i) the name of the borehole; (ii) parameter name; (iii) observation or sensor depth; (iv) unsaturated zone model layer; (v) number of observations, minimum, maximum, average, and standard deviation of the parameter, (vi) aggregation process, and (vii) Data Tracking Numbers (DTNs) where the data are identified. The summary table should include saturation, water potential, and pneumatic pressure data. If a data value is aggregated from a set of observations or measurements, describe and justify the data selection and aggregation process. This information is needed to evaluate compliance with 10 CFR 63.114(a) and (b).

Basis: Neither the SAR nor supporting AMR (SNL, 2007, *Calibrated Unsaturated Zone Properties*) provides information sufficient to evaluate the adequacy of data for calibrating the site-scale model. SNL (2007, Table 6-4) describes the observations by listing the boreholes with observations and pointing to the DTNs supplying the data. SNL (2007, Figures 6-1 through 6-8) also plots observations from 5 of the 19 boreholes having saturation or water potential observations used in the calibrations. However, these figures do not indicate the individual model layers. Also SNL (2007) does not provide the observations or model estimates for the remaining boreholes. Therefore, the extent to which parameters in individual model layers are based on observations is not clear, nor is it clear how consistently the observations support model predictions among boreholes.

Further, SAR Section 2.3.2.4.1 and the supporting AMR (SNL, 2007) do not consistently represent the source of the input data. For example, SAR Section 2.3.2.4.1 states that 16 boreholes are used for one-dimensional calibration of drift-scale matrix properties but SNL (2007) identifies 16 (SNL, 2007, Section 6.3.2), 19 (SNL, 2007, Table 6-4), and 23 (SNL, 2007, Appendix D) boreholes as being used to estimate drift-scale properties, and SAR Section 2.3.2.4.1 identifies 2 boreholes used for one-dimensional calibration of mountain-scale fracture permeability but SNL (2007, Section 6.3.3) identifies 5 boreholes. Also, SNL (2007, Table 6-4) does not indicate a source for matrix saturations in SD-12 but SNL (2007, Figures 6-1, 6-3, 6-5, and 6-7) plots a set of measured matrix saturations in SD-12.

1. RESPONSE

1.1 UNSATURATED ZONE PROPERTY CALIBRATION PROCEDURE

The unsaturated zone (UZ) property calibration procedure involved several steps. First, representative, uncalibrated fracture and matrix properties were developed for different unsaturated zone model layers based on field and laboratory measurements of hydraulic properties. Second, one-dimensional inverse modeling was used to calibrate some fracture and matrix properties, so that such modeling produced results consistent with field measurements of matrix saturation and water potential. Finally, these properties were further adjusted by direct comparisons between simulation results (obtained from the three-dimensional unsaturated zone flow model) and additional observations (including perched water and barometric response) so that observed characteristics of three-dimensional flow behavior are captured in developed property sets.

Uncalibrated properties for both fractures and matrix include permeability, porosity, and van Genuchten parameters. The development of these properties for unsaturated zone model layers is described in SAR Section 2.3.2.3.3. Uncalibrated properties (e.g., permeability) are available for most of the model layers. However, the site-scale unsaturated zone flow model does not directly use such properties because properties are sampled at scales much smaller than the property resolution scales required for a site-scale model. Also, some of the needed hydrologic properties (e.g., fracture van Genuchten parameters) are not directly measured. Consequently, model calibration was used to develop hydrologic properties for site-scale unsaturated zone flow model before its use in subsequent flow and transport studies.

The calibration procedure refined the prior, uncalibrated estimates derived from laboratory and field data for suitable use in the unsaturated zone flow model (SNL 2007a, Section 6.1.2). The calibration method uses an inverse modeling method that requires many forward simulations. Because this is computationally intensive, one-dimensional columnar models were used for the initial calibrations instead of the full three-dimensional model to reduce the time required for each forward simulation. Several types of rock-property information were used in the one-dimensional calibration (SNL 2007a, Section 6.2.4). If the one-dimensional calibrated parameters were to be directly used in three-dimensional simulations, they may not predict lateral flow or water perching in the unsaturated zone of Yucca Mountain. Therefore, to ensure the calibration was suitable, the calibrated parameters developed in *Calibrated Unsaturated Zone Properties* (SNL 2007a) were further calibrated using the three-dimensional, mountain-scale, unsaturated zone model documented in *UZ Flow Models and Submodels* (SNL 2007b). Rock parameter sets were developed for both the mountain and drift scales because of the scale-dependent behavior of fracture permeability. These parameter sets, except those for faults (which were determined using two-dimensional simulation), were first developed using one-dimensional simulations and then re-calibrated with the three-dimensional model.

Observations of perching below the repository elevation were not used for one-dimensional calibration because they are associated with lateral flow behavior. Accordingly, the last step of the calibration was to locally adjust hydrologic properties for several grid layers of the lower basal vitrophyre of the Topopah Spring welded (TSw) unit and for the upper layers in the zeolitic

Calico Hills nonwelded (CHn) unit so that three-dimensional simulation results match the observed occurrence and extent of perched water. The one-dimensional calibration process is described in SAR Section 2.3.2.4.1.2.3 (and SNL 2007a), and the three-dimensional calibration process is described in SAR Section 2.3.2.4.1.2.4.4 (and SNL 2007b, Section 6.2). Table 1 lists boreholes and data types used for property calibrations. Matrix water saturation and *in situ* water potential data from 23 boreholes were used for the one-dimensional calibrations for the drift-scale property sets for each infiltration uncertainty case. Matrix water saturation data were obtained for 20 boreholes, and *in situ* water potential data were obtained from four boreholes, with one borehole in common (SD-12), for the one-dimensional calibrations of the drift-scale property sets.

Table 1. Boreholes and Data Types used in Property Calibrations

One-Dimensional Calibration for Drift-Scale Property Sets	
Data Type	Boreholes Used
Matrix Saturation	USW SD-6, USW SD-7, USW SD-9, USW SD-12, USW UZ-14, UE-25 UZ#16, USW UZ-N11, USW UZ-N31, USW UZ-N32, USW UZ-N33, USW UZ-N37, USW UZ-N38, USW UZ-N53, USW UZ-N54, USW UZ-N55, USW UZ-N57, USW UZ-N58, USW UZ-N59, USW UZ-N61, and USW WT-24
<i>In situ</i> Water Potential	USW SD-12, UE-25 UZ#4, USW NRG-6, and USW NRG-7a
Additional Two- and Three-Dimensional Calibrations for Site-Scale Fracture Permeability, Fault Zone Permeability, and Perched Water	
Pneumatic Pressure Time-Series (for calibrating site-scale fracture permeability)	USW SD-7, USW SD-12, UE-25 NRG#5, USW NRG-6, and USW NRG-7a
Matrix Saturation, <i>In situ</i> Water Potential, and Pneumatic Pressure Time Series (for calibrating fault-zone permeability)	USW UZ-7a
Perched Water Below the Repository Elevation (SNL 2007b, Sections 6.2.2.2 and 6.2.3)	As observed in USW SD-7, USW SD-9, USW SD-12, USW UZ-14, USW NRG-7a, USW G-2, and USW WT-24

1.2 SUMMARY TABLES OF THE WATER SATURATION AND POTENTIALS

This section presents the data tabulation requested in the RAI, as further defined in the clarification call with NRC staff (April 28, 2009), for matrix saturation and *in situ* water potential data. Graphical pneumatic pressure data are presented in the next section. For each aggregated data item constraining measured saturation and *in situ* water potential in the one-dimensional calibrations, Tables 2 to 25 provide: the name of the borehole, the parameter name, the depth assigned to the data, and the unsaturated zone model layer.

For the calibration process, matrix saturation data from core samples need to be compared with saturation profiles generated by the numerical model for intervals as large as several tens of meters (corresponding to model grid thickness). To make this comparison, the measured saturations are averaged over model grid depth intervals. These average values of the saturation data are presented in Tables 2 to 21 in the column labeled “Measured Saturation”. The averaged data and the associated uncertainty estimates were inputs to the calibration process (SNL 2007a, Section 6.3).

The uncertainty for matrix saturation is defined as:

$$TE = SE + ME + HE \quad (\text{Eq. 1})$$

where TE is the total error, SE is the standard error, ME is the measurement error, and HE is the handling error. Standard error, SE , is defined as:

$$SE = \frac{\sigma}{\sqrt{N}} \quad (\text{Eq. 2})$$

where σ is the unbiased estimate of the standard deviation and N is the number of measurements. The errors ME and HE were estimated from analysis of the saturation measurements (SNL 2007a, Section 6.2.2).

Tables 2 to 21 provide the aggregated matrix saturation data used for the one-dimensional drift-scale property calibrations for each borehole and hydrologic unit represented (SNL 2007a, Appendix D). The water saturation and water potential data constrain the calibration model calculations and therefore are referred to as constraint data. Constraint data uncertainty values were calculated with Equation 1. Constraint data are not available for every hydrologic unit in every borehole, so some hydrologic units are represented by multiple aggregated data points (corresponding to different model gridblocks) in some boreholes. Model layer and depth of the grid point corresponding to each constraint data value, along with the corresponding optimized simulation results for matrix saturation for the 10th, 30th, 50th, and 90th percentile present-day infiltration maps (SNL 2007a, Section 6.3) are also tabulated.

The *in situ* water-potential data were measured at depth intervals equal to or greater than the numerical grid spacing, and because water potential is more spatially uniform *in situ*, these data were not averaged. However, water potential values were picked from time series data to represent steady-state conditions. These steady-state values have been compared to more recent

water potential measurements (SNL 2007a, Appendix A). The comparisons indicate that the equilibrium (steady-state) water potential values used for calibration, based on data collected prior to March 1998, are consistent with the more recent data. The measurement error for *in situ* water potential (P_c) is estimated to be 0.1 MPa (or 1 bar; SNL 2007a, Section 6.2.2). Because values for $\log(P_c)$ were used in one-dimensional inversions, the standard errors were converted to the standard error of $\log(P_c)$ using:

$$SE_{\log(P_c)} = \frac{\log(|P_c| + 1 \text{ bar}) - \log(|P_c| - 1 \text{ bar})}{2} \text{ for } -P_c > 1 \text{ bar} \quad (\text{Eq. 3a})$$

$$SE_{\log(P_c)} = \log(|P_c| + 1 \text{ bar}) - \log(|P_c|) \text{ for } -P_c \leq 1 \text{ bar} \quad (\text{Eq. 3b})$$

Tables 22 to 25 provide the steady-state *in situ* water potential data used for the one-dimensional calibrations, expressed as $-\log(P_c)$, for each borehole and measurement point included (SNL 2007a, Section 6.3.2). The model layer and depth of the grid point corresponding to each constraint data value, along with the corresponding optimized simulation results for *in situ* water potential for the 10th, 30th, 50th, and 90th percentile present-day infiltration maps (SNL 2007a, Section 6.3) are also tabulated. When a water potential measurement was made close to the interface between two adjacent grid blocks, the same measurement was assigned to the two grid blocks. This treatment is reasonable considering that measured $\log(P_c)$ values vary relatively smoothly along the vertical direction.

Data in Tables 2 to 25 are directly from DTNs: LB0610UZDSCP10.001, LB0610UZDSCP30.001, LB0611UZDSCP50.001, and LB0612UZDSCP90.001 for the 10th, 30th, 50th, and 90th percentile infiltration scenarios, respectively. Elevation values needed to derive depth values given in Tables 2 to 25 are from DTN: MO0012MWDGFM02.002.

ENCLOSURE 1

Response Tracking Number: 00333-00-00

RAI: 3.2.2.1.3.6-001

Table 2. Measured and Simulated Matrix Saturations for Borehole USW SD-6

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	117.60	0.81875	0.0438	0.95924	0.95690	0.98127	0.98661
tcwM3	128.40	0.99333	0.0302	0.96330	0.96100	0.96345	0.97164
ptnM1	131.30	0.80000	0.0716	0.60081	0.58782	0.61286	0.64365
ptnM1	132.70	0.65000	0.0676	0.61084	0.59596	0.62053	0.65094
ptnM1	134.00	0.40000	0.0608	0.62083	0.60178	0.62391	0.65155
ptnM2	136.70	0.28667	0.0344	0.58208	0.57085	0.57063	0.55976
ptnM4	140.60	0.31750	0.0507	0.50905	0.52020	0.51231	0.52613
ptnM4	144.30	0.28000	0.0176	0.49197	0.50565	0.50317	0.51377
ptnM5	147.50	0.28000	0.0576	0.46397	0.48956	0.54182	0.47825
ptnM6	150.70	0.43250	0.1870	0.55354	0.58573	0.59196	0.61893
ptnM6	154.50	0.33500	0.0440	0.54718	0.58150	0.58338	0.61230
ptnM6	158.20	0.53500	0.1390	0.53430	0.57190	0.56158	0.59690
tswM1	161.10	0.46000	0.0624	0.72873	0.77178	0.85607	0.73405
tswM2	169.70	0.41889	0.0229	0.59953	0.63026	0.67298	0.70345
tswM5	388.20	0.77200	0.0370	0.95675	0.95524	0.97056	0.93554
tswM6	405.30	0.82833	0.0517	0.95755	0.98572	0.99588	0.99901
tswM7	436.00	0.79250	0.0534	0.95898	0.99043	0.99690	0.99916
tswM8	450.80	0.83000	0.0375	0.98005	0.95126	0.96434	0.97020
tswMv	460.60	0.77000	0.0866	0.48925	0.46949	0.52172	0.56258
ch1Mv	465.20	0.43000	0.0516	0.42906	0.40755	0.43941	0.47813
ch1Mv	473.60	0.29000	0.0578	0.47062	0.39944	0.44669	0.46550
ch2Mv	479.60	0.35375	0.0845	0.58398	0.46908	0.54120	0.54604
ch3mv	487.40	0.27500	0.0324	0.58278	0.47079	0.54107	0.54774
ch4Mv	495.30	0.33000	0.0618	0.57741	0.47375	0.54066	0.55178
ch6Mv	514.84	0.60500	0.0813	0.79553	0.79751	0.85190	0.86964
pp4Mz	526.41	0.55500	0.1280	0.89935	0.91503	0.99827	1.00000
pp3Md	536.91	0.23000	0.0160	0.35913	0.37901	0.38261	0.41416
pp3Md	550.33	0.21500	0.0173	0.37944	0.40449	0.40564	0.43903
pp3Md	563.75	0.25545	0.0228	0.43172	0.46750	0.47152	0.50414
pp2Md	575.96	0.43600	0.0254	0.89406	0.92256	0.93984	0.98372
pp1Mz	638.63	0.95000	0.0757	0.91207	0.92958	0.94129	0.94903
bf3Md	656.45	0.26833	0.0338	0.72440	0.65291	0.67873	0.71594

ENCLOSURE 1

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Table 3. Measured and Simulated Matrix Saturations for Borehole USW SD-7

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	10.50	0.95125	0.0526	0.73794	0.73861	0.77872	0.82726
tcwM2	28.80	0.90471	0.0458	0.76820	0.76775	0.80630	0.85417
tcwM2	47.10	0.86953	0.0394	0.80365	0.80031	0.83193	0.87460
tcwM2	65.40	0.74380	0.0381	0.84837	0.84218	0.86308	0.89560
tcwM2	83.70	0.87819	0.0403	0.90622	0.89970	0.90842	0.92464
tcwM3	94.50	0.98767	0.0304	0.96232	0.95820	0.96196	0.96948
ptnM1	98.50	0.38850	0.0280	0.60572	0.58507	0.61136	0.63389
ptnM2	100.00	0.52900	0.0643	0.55716	0.55264	0.56383	0.55274
ptnM4	102.60	0.56633	0.0642	0.47061	0.48705	0.49054	0.50352
ptnM6	110.70	0.40550	0.0454	0.53108	0.56634	0.57553	0.60592
ptnM6	115.40	0.52600	0.0642	0.52245	0.55960	0.55657	0.59344
tswM1	118.70	0.62550	0.1360	0.72070	0.76004	0.85657	0.73663
tswM2	126.30	0.46386	0.0266	0.57388	0.60067	0.66447	0.69515
tswM2	139.60	0.53254	0.0318	0.61724	0.63916	0.65941	0.70579
tswM3	154.00	0.62700	0.0491	0.84435	0.85009	0.83745	0.87524
tswM3	169.40	0.74513	0.0397	0.84512	0.85113	0.84572	0.88104
tswM3	184.80	0.80653	0.0415	0.84647	0.85211	0.85681	0.88689
tswM3	200.20	0.89731	0.0351	0.84966	0.85293	0.87807	0.89575
tswM4	217.10	0.93440	0.0318	0.95832	0.97023	0.99136	0.99583
tswM4	235.60	0.94305	0.0329	0.96246	0.97521	0.99104	0.99793
tswM5	246.30	0.88100	0.0738	0.94086	0.95182	0.96041	0.93145
tswM5	250.30	0.92150	0.0294	0.94097	0.95194	0.96131	0.93237
tswM5	255.30	0.85133	0.0733	0.94102	0.95193	0.96224	0.93329
tswM5	260.30	0.85520	0.0411	0.94097	0.95169	0.96301	0.93416
tswM5	265.30	0.84220	0.0560	0.94075	0.95108	0.96360	0.93498
tswM5	270.30	0.88233	0.0329	0.94024	0.94993	0.96391	0.93572
tswM5	282.40	0.87837	0.0334	0.93794	0.94514	0.96362	0.93697
tswM5	301.40	0.91556	0.0382	0.92673	0.92382	0.95342	0.91580
tswM6	319.20	0.92453	0.0306	0.91420	0.96994	0.99093	0.99771
tswM6	335.60	0.91021	0.0335	0.91752	0.97677	0.99308	0.99847
tswM7	352.10	0.90461	0.0319	0.92355	0.98397	0.99520	0.99902
tswM8	368.11	0.92475	0.0396	0.97063	0.94260	0.96320	0.97228
tswM8	383.75	0.83447	0.0402	0.96497	0.93743	0.95938	0.97000
tswMv	395.10	0.63229	0.0687	0.44651	0.44948	0.50404	0.54948
ch1Mv	401.10	0.30817	0.0199	0.38600	0.39280	0.42419	0.46950
ch1Mv	406.03	0.32860	0.0473	0.39007	0.39312	0.42515	0.47009
ch1Mv	410.97	0.37900	0.0154	0.39557	0.39303	0.42595	0.46981

ENCLOSURE 1

Response Tracking Number: 00333-00-00

RAI: 3.2.2.1.3.6-001

Table 3. Measured and Simulated Matrix Saturations for Borehole USW SD-7 (continued)

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
ch1Mv	425.77	0.27767	0.0468	0.43728	0.39088	0.43326	0.45844
ch2Mv	434.39	0.33000	0.0399	0.56126	0.46941	0.53334	0.54217
ch3Mv	446.69	0.40362	0.0379	0.56579	0.48907	0.54223	0.55719
ch4Mv	458.99	0.80700	0.0636	0.58850	0.53760	0.57832	0.61488
pp4Mz	497.78	0.97650	0.0353	0.73769	0.70880	0.78693	0.85453
pp3Md	510.58	0.39560	0.0657	0.32108	0.30280	0.35763	0.39815
pp3Md	528.64	0.28616	0.0199	0.34214	0.33454	0.39403	0.43275
pp2Md	545.82	0.65294	0.0608	0.77910	0.79710	0.87194	0.95670
pp2Md	562.10	0.81694	0.0542	0.86604	0.88959	0.91902	0.97523
pp1Mz	578.21	0.83094	0.0422	0.93469	0.95049	0.98344	0.98672
pp1Mz	594.15	0.81671	0.0440	0.92666	0.94549	0.95508	0.95721
pp1Mz	610.09	0.92472	0.0324	0.92579	0.94160	0.94787	0.94905
pp1Mz	626.03	0.95582	0.0318	0.93012	0.88694	0.94909	0.95022

Table 4. Measured and Simulated Matrix Saturations for Borehole USW SD-9

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	9.50	0.97600	0.0764	0.87719	0.87734	0.88153	0.89373
tcwM3	20.60	0.93986	0.0516	0.94137	0.94323	0.94901	0.96183
ptnM1	24.30	0.67000	0.0681	0.55411	0.55177	0.57997	0.61470
ptnM1	25.80	0.52700	0.0272	0.55957	0.55497	0.58255	0.61699
ptnM1	27.30	0.55100	0.0649	0.56362	0.55345	0.57780	0.60892
ptnM2	29.80	0.45967	0.0838	0.50702	0.50074	0.50432	0.50047
ptnM2	33.10	0.54775	0.0710	0.52790	0.52120	0.52454	0.52063
ptnM3	35.50	0.74750	0.1140	0.69492	0.69736	0.70488	0.71766
ptnM3	37.00	0.69700	0.0688	0.71314	0.71627	0.72317	0.73543
ptnM4	40.20	0.45533	0.0445	0.47541	0.49080	0.48629	0.50465
ptnM4	45.10	0.47075	0.0406	0.45564	0.46609	0.46668	0.48481
ptnM5	49.70	0.34200	0.0308	0.37148	0.35818	0.40295	0.38064
ptnM5	54.10	0.34200	0.0592	0.37494	0.36830	0.41164	0.38582
ptnM5	58.40	0.24550	0.0081	0.38065	0.38339	0.42617	0.39496
ptnM5	62.70	0.31050	0.0119	0.39014	0.40622	0.45082	0.41128
ptnM5	67.10	0.35550	0.0218	0.40604	0.44189	0.49410	0.44118
ptnM6	71.40	0.30867	0.0295	0.52415	0.56315	0.57153	0.60108
ptnM6	75.60	0.25950	0.0129	0.51965	0.55943	0.56362	0.59524
ptnM6	79.90	0.46450	0.0824	0.51157	0.55166	0.54484	0.58229
tswM1	83.00	0.69800	0.0688	0.70326	0.74446	0.84188	0.71924
tswM2	92.90	0.69079	0.0509	0.54252	0.58371	0.64956	0.67993
tswM2	110.70	0.54000	0.0380	0.56736	0.61243	0.65662	0.69282
tswM2	128.40	0.76027	0.0344	0.60426	0.64534	0.65011	0.70136
tswM3	145.80	0.81550	0.0376	0.83475	0.85860	0.82459	0.86933
tswM3	162.90	0.71444	0.0438	0.83512	0.85924	0.83116	0.87419
tswM3	180.00	0.73347	0.0310	0.83544	0.85961	0.83850	0.87844
tswM3	197.00	0.86150	0.0384	0.83564	0.85913	0.84971	0.88165
tswM3	214.10	0.85193	0.0487	0.83543	0.85591	0.87430	0.88127
tswM4	223.30	0.92950	0.0536	0.94753	0.96900	0.98662	0.99140
tswM4	226.50	0.92075	0.0301	0.94821	0.96986	0.98719	0.99256
tswM4	231.50	0.90667	0.0948	0.94924	0.97106	0.98785	0.99387
tswM4	236.50	0.91380	0.0493	0.95034	0.97223	0.98833	0.99490
tswM4	241.50	0.94300	0.0645	0.95156	0.97337	0.98861	0.99575
tswM4	246.50	0.88220	0.0364	0.95296	0.97452	0.98865	0.99647
tswM4	253.40	0.93022	0.0349	0.95524	0.97614	0.98826	0.99740
tswM5	266.50	0.89078	0.0477	0.93374	0.95399	0.95584	0.92997
tswM5	283.60	0.81900	0.0405	0.93422	0.95470	0.95863	0.93214

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Table 4. Measured and Simulated Matrix Saturations for Borehole USW SD-9 (continued)

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tswM5	300.60	0.80591	0.0396	0.93436	0.95480	0.96074	0.93407
tswM5	317.73	0.91293	0.0369	0.93357	0.95327	0.96167	0.93569
tswM5	334.82	0.80780	0.0427	0.93000	0.94706	0.95949	0.93546
tswM5	351.91	0.86343	0.0360	0.91808	0.92692	0.94719	0.90987
tswM6	369.39	0.87577	0.0383	0.90209	0.97273	0.98918	0.99721
tswM6	387.28	0.87227	0.0369	0.90738	0.98013	0.99240	0.99826
tswM7	405.16	0.92407	0.0468	0.91785	0.98783	0.99555	0.99903
tswM8	423.30	0.85325	0.0382	0.97200	0.96122	0.97489	0.98148
pp4Mz	562.39	0.97167	0.0302	0.90953	0.74144	0.92814	0.94885
pp3Md	570.92	0.91600	0.0561	0.96869	0.49338	0.96712	0.96342

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Table 5. Measured and Simulated Matrix Saturations for Borehole USW SD-12

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	13.20	0.73420	0.0619	0.76669	0.76159	0.78093	0.82253
tcwM2	30.30	0.69419	0.0454	0.80319	0.79767	0.81435	0.85244
tcwM2	47.40	0.80047	0.0623	0.84764	0.84143	0.85219	0.88081
tcwM2	64.50	0.76694	0.0554	0.90319	0.89844	0.90299	0.91734
tcwM3	75.50	0.94800	0.0449	0.96107	0.95871	0.96153	0.96911
ptnM1	78.80	0.57250	0.0380	0.59755	0.58507	0.61113	0.63798
ptnM1	80.40	0.73400	0.1180	0.61031	0.59657	0.62358	0.64902
ptnM4	83.00	0.55467	0.0617	0.46212	0.48206	0.48520	0.49894
ptnM5	86.90	0.50450	0.0404	0.42118	0.45649	0.50747	0.45185
ptnM6	90.50	0.54667	0.1050	0.53113	0.56814	0.57441	0.60417
ptnM6	93.90	0.32867	0.0246	0.52611	0.56421	0.56587	0.59797
ptnM6	97.30	0.54067	0.0788	0.51750	0.55662	0.54740	0.58539
tswM1	100.00	0.73900	0.0700	0.71244	0.75354	0.84746	0.72573
tswM2	109.00	0.41740	0.0240	0.56498	0.59935	0.65494	0.68652
tswM2	125.10	0.55494	0.0317	0.60912	0.64054	0.65114	0.69905
tswM3	141.70	0.64980	0.0479	0.83926	0.85368	0.82788	0.86899
tswM3	159.00	0.71107	0.0450	0.84000	0.85482	0.83623	0.87508
tswM3	176.30	0.82456	0.0438	0.84114	0.85595	0.84701	0.88095
tswM3	193.60	0.86870	0.0492	0.84369	0.85710	0.86761	0.88889
tswM4	211.70	0.86818	0.0381	0.95487	0.97170	0.98926	0.99490
tswM4	230.50	0.85947	0.0353	0.95905	0.97606	0.98992	0.99733
tswM5	248.40	0.88800	0.0406	0.93869	0.95461	0.95825	0.93156
tswM5	265.40	0.85220	0.0430	0.93903	0.95486	0.96087	0.93399
tswM5	282.40	0.86120	0.0381	0.93840	0.95311	0.96200	0.93600
tswM5	299.40	0.88520	0.0416	0.93487	0.94566	0.95934	0.93586
tswM5	316.40	0.87829	0.0688	0.92237	0.92098	0.94420	0.90666
tswM6	332.07	0.78831	0.0548	0.90832	0.96629	0.98708	0.99679
tswM6	346.45	0.83747	0.0371	0.90910	0.97092	0.98902	0.99754
tswM6	360.83	0.84755	0.0530	0.90998	0.97597	0.99096	0.99812
tswM7	373.42	0.88157	0.0349	0.91092	0.98075	0.99268	0.99853
tswM7	384.20	0.88864	0.0435	0.91205	0.98506	0.99420	0.99883
tswM8	394.14	0.89371	0.0468	0.96323	0.93559	0.95048	0.95924
tswMv	403.20	0.65630	0.0750	0.44791	0.45188	0.49664	0.54269
ch1Mv	409.96	0.27000	0.0321	0.38885	0.39484	0.41844	0.46368
ch1Mv	414.47	0.20860	0.0124	0.39478	0.39573	0.41982	0.46395
ch1Mv	418.97	0.23133	0.0155	0.40302	0.39661	0.42150	0.46326
ch1Mv	423.47	0.30100	0.0177	0.41519	0.39775	0.42423	0.46132

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Table 5. Measured and Simulated Matrix Saturations for Borehole USW SD-12 (continued)

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
ch1Mv	427.98	0.34275	0.0200	0.43377	0.39940	0.42902	0.45704
ch2Mv	437.40	0.31040	0.0317	0.56231	0.48185	0.53396	0.54687
ch3Mv	451.73	0.59533	0.0779	0.58235	0.52598	0.56451	0.59119
ch5Mv	480.40	0.84173	0.0623	0.68087	0.92843	0.94279	0.96387
pp4Mz	506.85	0.94633	0.0612	0.75488	0.73372	0.80308	0.86544
pp3Md	519.56	0.29661	0.0196	0.32778	0.32104	0.35600	0.39454
pp3Md	536.33	0.32800	0.0164	0.36079	0.36701	0.40132	0.43679
pp2Md	550.66	0.63630	0.0753	0.81321	0.83917	0.87924	0.95884
pp2Md	562.54	0.86477	0.0466	0.89344	0.91639	0.93015	0.97818
pp1Mz	574.74	0.95462	0.0423	0.93502	0.95104	0.98309	0.98718
pp1Mz	587.27	0.99500	0.0308	0.93222	0.89019	0.95813	0.96102

Table 6. Measured and Simulated Matrix Saturations for Borehole USW UZ-14

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
ptnM2	12.10	0.92700	0.0980	0.51403	0.51000	0.50465	0.49915
ptnM2	15.10	0.92700	0.0346	0.53554	0.53173	0.52431	0.51888
ptnM3	17.20	0.89400	0.0741	0.70390	0.71168	0.70045	0.71070
ptnM3	18.20	0.94300	0.0755	0.71766	0.72620	0.71335	0.72356
ptnM4	20.80	0.99700	0.0299	0.47417	0.49255	0.47660	0.49368
ptnM4	25.00	0.63300	0.0660	0.46565	0.48118	0.46779	0.48526
ptnM4	29.20	0.61300	0.0506	0.44662	0.45557	0.44876	0.46647
ptnM5	33.70	0.54360	0.0434	0.35687	0.33470	0.37088	0.35384
ptnM5	38.30	0.48300	0.0322	0.35734	0.33672	0.37221	0.35450
ptnM5	43.00	0.46100	0.0230	0.35810	0.33971	0.37434	0.35560
ptnM5	47.60	0.42900	0.0394	0.35935	0.34416	0.37775	0.35745
ptnM5	52.30	0.46400	0.0348	0.36140	0.35075	0.38320	0.36058
ptnM5	57.00	0.52880	0.0339	0.36479	0.36058	0.39198	0.36586
ptnM5	61.60	0.57040	0.0263	0.37037	0.37534	0.40618	0.37485
ptnM5	66.30	0.50620	0.0308	0.37963	0.39782	0.42951	0.39029
ptnM5	70.90	0.49960	0.0334	0.39512	0.43322	0.46909	0.41745
ptnM6	75.40	0.34600	0.0479	0.51846	0.55848	0.55658	0.58564
ptnM6	79.70	0.30300	0.0173	0.51530	0.55567	0.55015	0.58200
ptnM6	83.90	0.32700	0.0588	0.50981	0.54996	0.53617	0.57459
tswM1	87.10	0.73150	0.2880	0.70697	0.74737	0.84362	0.72281
tswM2	95.30	0.59527	0.0581	0.53921	0.57566	0.64151	0.66812
tswM2	109.90	0.40687	0.0246	0.55975	0.60033	0.64204	0.67454
tswM2	124.50	0.64950	0.0488	0.59212	0.62972	0.62698	0.67643
tswM3	140.40	0.80461	0.0466	0.81928	0.84192	0.80372	0.84646
tswM3	157.60	0.78742	0.0514	0.81961	0.84266	0.80853	0.85030
tswM3	174.90	0.88221	0.0332	0.81986	0.84316	0.81374	0.85373
tswM3	192.10	0.89529	0.0415	0.81987	0.84295	0.82086	0.85640
tswM3	209.30	0.86200	0.0397	0.81911	0.84054	0.83426	0.85634
tswM4	226.60	0.89929	0.0407	0.93869	0.96332	0.97771	0.98846
tswM4	243.80	0.87342	0.0454	0.94384	0.96840	0.97958	0.99374
tswM5	260.90	0.74855	0.0593	0.92285	0.94503	0.94046	0.91213
tswM5	277.80	0.80567	0.0615	0.92328	0.94580	0.94295	0.91430
tswM5	288.80	0.81200	0.0777	0.92327	0.94578	0.94383	0.91502
tswM5	293.80	0.84240	0.0554	0.92316	0.94559	0.94424	0.91563
tswM5	298.80	0.82020	0.0449	0.92289	0.94514	0.94442	0.91622
tswM5	303.80	0.88933	0.0323	0.92238	0.94430	0.94429	0.91674
tswM5	308.80	0.79575	0.0559	0.92150	0.94287	0.94365	0.91708

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Table 6. Measured and Simulated Matrix Saturations for Borehole USW UZ-14 (continued)

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tswM5	320.40	0.85288	0.0347	0.91812	0.93747	0.94042	0.91592
tswM5	338.60	0.89087	0.0382	0.90488	0.91641	0.92300	0.87572
tswM6	354.79	0.90809	0.0408	0.88591	0.97079	0.98204	0.99414
tswM6	368.88	0.88883	0.0412	0.89383	0.97866	0.98730	0.99620
tswM7	382.97	0.91864	0.0384	0.90784	0.98647	0.99233	0.99793
tswM8	395.95	0.94773	0.0641	0.96886	0.95164	0.95649	0.96199
tswM8	407.84	0.94445	0.0406	0.97292	0.96440	0.97207	0.97856
pp4Mz	544.35	0.92253	0.0568	0.76887	0.70321	0.84096	0.88760
pp3Md	559.67	0.83409	0.0698	0.65411	0.41809	0.64682	0.63218
pp2Md	567.02	0.98375	0.0317	0.99033	0.86081	0.99122	0.99667

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Table 7. Measured and Simulated Matrix Saturations for Borehole UE-25 UZ#16

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	20.80	0.79431	0.0586	0.81113	0.82529	0.82220	0.82873
tcwM2	35.90	0.86843	0.0378	0.85438	0.87760	0.87650	0.88258
tcwM3	45.30	0.82600	0.0723	0.91866	0.93838	0.94012	0.95032
ptnM1	47.70	0.67400	0.0682	0.51622	0.53627	0.55366	0.57363
ptnM1	48.90	0.55900	0.0761	0.51968	0.54114	0.55853	0.57720
ptnM2	51.50	0.38375	0.0664	0.46581	0.50794	0.51336	0.50194
ptnM4	55.70	0.44600	0.0456	0.40632	0.45855	0.45776	0.46820
ptnM6	60.10	0.32275	0.0391	0.47500	0.52985	0.53128	0.56259
ptnM6	64.10	0.23800	0.0150	0.47741	0.52854	0.52604	0.56036
ptnM6	68.20	0.32220	0.0773	0.48061	0.52633	0.51645	0.55644
tswM1	71.20	0.91000	0.1150	0.67120	0.71542	0.82472	0.70225
tswM2	81.50	0.40267	0.0240	0.48478	0.53068	0.61209	0.63837
tswM2	100.00	0.50300	0.0425	0.50190	0.55754	0.59233	0.63766
tswM3	118.80	0.67291	0.0506	0.71301	0.76504	0.76668	0.80756
tswM3	137.80	0.65475	0.0425	0.70865	0.76110	0.76991	0.80803
tswM3	156.80	0.74376	0.0351	0.69759	0.74881	0.77353	0.79935
tswM4	175.80	0.90653	0.0336	0.84173	0.91140	0.95081	0.97421
tswM4	194.70	0.90741	0.0343	0.85143	0.92340	0.95654	0.98646
tswM5	212.30	0.78300	0.0374	0.83571	0.89371	0.90714	0.88108
tswM5	228.50	0.77275	0.0493	0.83420	0.89249	0.90802	0.88314
tswM5	244.73	0.72494	0.0508	0.83089	0.88812	0.90614	0.88450
tswM5	260.97	0.79756	0.0514	0.82399	0.87700	0.89794	0.88005
tswM5	277.20	0.82147	0.0461	0.80992	0.85122	0.87440	0.82321
tswM6	294.09	0.89447	0.0374	0.73364	0.92912	0.95964	0.98588
tswM6	311.63	0.91288	0.0352	0.73626	0.94765	0.97234	0.99139
tswM7	329.18	0.85161	0.0362	0.74110	0.96638	0.98440	0.99592
tswM8	346.72	0.92131	0.0406	0.90754	0.91735	0.94175	0.95837
pp4Mz	455.36	0.86875	0.0702	0.63723	0.59973	0.72553	0.83370
pp3Md	462.91	0.38258	0.0174	0.39578	0.32861	0.39469	0.39384
pp3Md	474.11	0.52085	0.0504	0.51663	0.37700	0.51225	0.50328
pp2Md	484.75	0.91400	0.0337	0.96601	0.84020	0.96936	0.98808

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Table 8. Measured and Simulated Matrix Saturations for Borehole USW WT-24

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tswM8	517.86	0.93961	0.0446	0.99010	0.97779	0.98629	0.98733

Table 9. Measured and Simulated Matrix Saturations for Borehole USW UZ-N11

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	56.60	0.95850	0.0674	0.90332	0.89654	0.91671	0.92364
tcwM3	65.10	0.71200	0.2760	0.95231	0.94681	0.95765	0.96344
ptnM1	66.60	0.44440	0.0933	0.56361	0.54551	0.58319	0.59910
ptnM2	69.80	0.41450	0.0187	0.49427	0.47711	0.49270	0.48216
ptnM2	74.50	0.27300	0.0284	0.50850	0.49066	0.50454	0.49322
ptnM2	79.20	0.34000	0.0882	0.53084	0.51080	0.52374	0.51124
ptnM3	82.60	0.57400	0.1920	0.70650	0.68449	0.70720	0.70445
ptnM3	84.60	0.50267	0.0489	0.71877	0.69932	0.71936	0.71530

Table 10. Measured and Simulated Matrix Saturations for Borehole USW UZ-N31

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	5.60	0.87364	0.0312	0.85146	0.84147	0.84076	0.85133
tcwM2	20.40	0.89274	0.0364	0.90205	0.89612	0.89634	0.90274
tcwM3	29.90	0.99200	0.0295	0.95640	0.95339	0.95538	0.96270
ptnM1	32.70	0.92425	0.0710	0.58081	0.56712	0.58816	0.60844
ptnM2	34.20	0.65675	0.0646	0.53002	0.53483	0.54370	0.53517
ptnM4	36.40	0.47267	0.0308	0.44675	0.46902	0.47012	0.48431
ptnM5	40.00	0.43480	0.0383	0.37840	0.40390	0.44923	0.40815
ptnM5	44.00	0.54433	0.0484	0.39272	0.43710	0.49054	0.43691
ptnM6	48.00	0.41800	0.0368	0.51602	0.55799	0.56666	0.59639
ptnM6	51.90	0.51140	0.0705	0.51334	0.55535	0.55956	0.59189
ptnM6	55.80	0.70280	0.0969	0.50888	0.55021	0.54379	0.58250

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Table 11. Measured and Simulated Matrix Saturations for Borehole USW UZ-N32

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	5.60	0.77480	0.0419	0.85146	0.84147	0.84076	0.85133
tcwM2	20.40	0.86450	0.0333	0.90205	0.89612	0.89634	0.90274
tcwM3	29.90	0.91333	0.0695	0.95640	0.95339	0.95538	0.96270
ptnM1	32.70	0.89550	0.0307	0.58081	0.56712	0.58816	0.60844
ptnM2	34.20	0.82000	0.0871	0.53002	0.53483	0.54370	0.53517
ptnM4	36.40	0.67140	0.0449	0.44675	0.46902	0.47012	0.48431
ptnM5	40.00	0.47380	0.0394	0.37840	0.40390	0.44923	0.40815
ptnM5	44.00	0.38050	0.0171	0.39272	0.43710	0.49054	0.43691
ptnM6	48.00	0.57260	0.0776	0.51602	0.55799	0.56666	0.59639
ptnM6	51.90	0.45700	0.0631	0.51334	0.55535	0.55956	0.59189
ptnM6	55.80	0.43600	0.0293	0.50888	0.55021	0.54379	0.58250
tswM1	58.80	0.52333	0.0331	0.70793	0.74947	0.84989	0.73002
tswM2	66.60	0.65860	0.1220	0.53836	0.57573	0.65197	0.68052

Table 12. Measured and Simulated Matrix Saturations for Borehole USW UZ-N33

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	3.50	0.95100	0.0757	0.90717	0.91416	0.91453	0.92539
tcwM3	5.90	0.97125	0.0313	0.94060	0.94471	0.94649	0.95955
ptnM1	8.20	0.96950	0.0307	0.54595	0.54606	0.56435	0.59463
ptnM1	9.90	0.79550	0.0684	0.55158	0.55072	0.56880	0.59957
ptnM1	11.50	0.65750	0.0463	0.55613	0.55201	0.56870	0.59828
ptnM1	13.20	0.59050	0.0884	0.55979	0.54978	0.56349	0.58958
ptnM2	15.60	0.48850	0.0437	0.50306	0.49771	0.49322	0.48678
ptnM2	18.90	0.81325	0.0752	0.52284	0.51735	0.51111	0.50442
ptnM3	21.20	0.48650	0.0536	0.68563	0.69020	0.68061	0.68816
ptnM3	22.70	0.66700	0.1070	0.70370	0.70906	0.69740	0.70459

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Table 13. Measured and Simulated Matrix Saturations for Borehole USW UZ-N37

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	13.70	0.88267	0.0379	0.83271	0.82880	0.82671	0.83830
tcwM2	26.40	0.86100	0.0514	0.87237	0.87284	0.87259	0.88488
tcwM3	34.60	0.85150	0.1390	0.92994	0.93080	0.93308	0.94844
ptnM1	37.00	0.42350	0.0459	0.53030	0.52467	0.54190	0.56926
ptnM1	38.10	0.40300	0.0609	0.53391	0.52740	0.54414	0.57067
ptnM2	41.00	0.46867	0.0579	0.48232	0.48774	0.49060	0.48802
ptnM4	45.40	0.27450	0.0099	0.41943	0.44099	0.43780	0.45502
ptnM5	49.90	0.22275	0.0236	0.32676	0.33825	0.37115	0.34799
ptnM5	54.70	0.20600	0.0143	0.33189	0.35190	0.38491	0.35684
ptnM5	59.50	0.24833	0.0237	0.33945	0.37127	0.40614	0.37121
ptnM5	64.30	0.33000	0.0231	0.35063	0.39956	0.43983	0.39503
ptnM6	68.60	0.49800	0.0435	0.49242	0.53556	0.53715	0.56932
ptnM6	72.40	0.29200	0.0505	0.49209	0.53387	0.53143	0.56649
ptnM6	76.20	0.38667	0.0686	0.49161	0.53103	0.52089	0.56148
tswM1	79.10	0.55250	0.0661	0.68504	0.72226	0.82961	0.70798
tswM2	88.80	0.71667	0.0282	0.50229	0.53715	0.62129	0.64744

Table 14. Measured and Simulated Matrix Saturations for Borehole USW UZ-N38

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	9.9	0.88321	0.0349	0.83663	0.83099	0.83102	0.84494
tcwM2	23.4	0.93486	0.0477	0.87952	0.87808	0.87990	0.89298

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Table 15. Measured and Simulated Matrix Saturations for Borehole USW UZ-N53

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	15.30	0.83015	0.0366	0.81244	0.81378	0.81238	0.82494
tcwM2	35.10	0.85574	0.0362	0.87135	0.88041	0.88017	0.88822
tcwM3	46.80	0.99050	0.0296	0.93850	0.94778	0.94996	0.95910
ptnM1	49.40	0.82550	0.0818	0.54388	0.55370	0.57365	0.59595
ptnM1	51.00	0.54800	0.1330	0.55055	0.56144	0.58116	0.60094
ptnM2	52.90	0.54133	0.0330	0.49787	0.52857	0.53534	0.52326
ptnM4	56.50	0.56314	0.0657	0.42878	0.47338	0.47362	0.48446
ptnM6	61.00	0.37900	0.0437	0.49186	0.54309	0.54723	0.57793
ptnM6	65.10	0.36083	0.0569	0.49172	0.54076	0.54076	0.57417
ptnM6	69.20	0.45486	0.1040	0.49150	0.53654	0.52775	0.56701

Table 16. Measured and Simulated Matrix Saturations for Borehole USW UZ-N54

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	15.30	0.79513	0.0449	0.81244	0.81378	0.81238	0.82494
tcwM2	35.10	0.85616	0.0348	0.87135	0.88041	0.88017	0.88822
tcwM3	46.80	0.84620	0.1050	0.93850	0.94778	0.94996	0.95910
ptnM1	49.40	0.40650	0.0285	0.54388	0.55370	0.57365	0.59595
ptnM1	51.00	0.50000	0.0479	0.55055	0.56144	0.58116	0.60094
ptnM2	52.90	0.45933	0.0570	0.49787	0.52857	0.53534	0.52326
ptnM4	56.50	0.52400	0.0347	0.42878	0.47338	0.47362	0.48446
ptnM6	61.00	0.39340	0.0609	0.49186	0.54309	0.54723	0.57793
ptnM6	65.10	0.42460	0.0615	0.49172	0.54076	0.54076	0.57417
ptnM6	69.20	0.52340	0.1270	0.49150	0.53654	0.52775	0.56701
tswM1	72.20	0.45550	0.2220	0.68538	0.72847	0.83364	0.71149
tswM2	81.90	0.38900	0.0485	0.50795	0.55354	0.62721	0.65556

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Table 17. Measured and Simulated Matrix Saturations for Borehole USW UZ-N55

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	9.60	0.76720	0.0458	0.77225	0.77443	0.77454	0.79383
tcwM2	27.10	0.80783	0.0383	0.81361	0.82088	0.82096	0.83684
tcwM2	44.60	0.89726	0.0360	0.86509	0.88020	0.88076	0.89093
tcwM3	55.30	0.97080	0.0362	0.93085	0.94449	0.94706	0.95772
ptnM1	58.30	0.86300	0.0923	0.53382	0.54977	0.57026	0.59547
ptnM1	60.30	0.61567	0.1120	0.54087	0.55822	0.57824	0.60074
ptnM2	62.80	0.37175	0.0360	0.48892	0.52613	0.53238	0.52147
ptnM4	65.70	0.44650	0.0678	0.41943	0.46629	0.46570	0.47751
ptnM6	69.00	0.42040	0.0367	0.48681	0.53709	0.53646	0.57064
ptnM6	72.90	0.60060	0.1080	0.48776	0.53342	0.52438	0.56418
tswM1	75.80	0.70967	0.1330	0.68064	0.72443	0.83098	0.70880
tswM2	85.70	0.53650	0.0330	0.49986	0.54701	0.62301	0.65127

Table 18. Measured and Simulated Matrix Saturations for Borehole USW UZ-N57

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tswM2	17.10	0.51314	0.0324	0.51086	0.54609	0.54582	0.58660
tswM2	27.90	0.54492	0.0354	0.55306	0.58299	0.56784	0.61963
tswM3	41.10	0.59833	0.0440	0.76990	0.79039	0.76323	0.80180

Table 19. Measured and Simulated Matrix Saturations for Borehole USW UZ-N58

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tswM2	12.80	0.44454	0.0307	0.51086	0.54609	0.54582	0.58660
tswM2	23.60	0.56307	0.0334	0.55306	0.58299	0.56784	0.61963
tswM3	36.80	0.48211	0.0593	0.76990	0.79039	0.76323	0.80180

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Table 20. Measured and Simulated Matrix Saturations for Borehole USW UZ-N59

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tswM2	13.70	0.44765	0.0373	0.50550	0.54617	0.55296	0.59505
tswM2	26.60	0.58000	0.0383	0.55027	0.58584	0.57608	0.62930
tswM3	40.80	0.59500	0.0371	0.76824	0.79426	0.76867	0.80947

Table 21. Measured and Simulated Matrix Saturations for Borehole USW UZ-N61

Model Layer	Depth (m)	Measured Saturation	Standard Deviation	Optimized Saturation Values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tswM2	13.10	0.47900	0.0479	0.50550	0.54617	0.55296	0.59505
tswM2	26.00	0.53606	0.0349	0.55027	0.58584	0.57608	0.62930
tswM3	40.20	0.58040	0.0675	0.76824	0.79426	0.76867	0.80947

Table 22. Measured and Simulated Matrix Water Potentials for Borehole USW NRG-7a

Model Layer	Depth (m)	Measured $-\log(P_c)^*$	Standard Deviation	Optimized $-\log(P_c)$ values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	15.90	4.98230	0.3	5.49240	5.42230	5.37770	5.32620
ptnM4	47.30	4.97770	0.3	5.01050	5.01940	5.01060	4.97850
tsM2	119.20	5.20410	0.3	5.45880	5.40490	5.04100	4.86560
tsM3	195.80	4.90850	0.3	5.26790	5.26570	5.29730	4.95860
tsM3	215.80	4.90850	0.3	5.27840	5.28810	5.26390	4.96960

* P_c = capillary pressure (Pa).

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Table 23. Measured and Simulated Matrix Water Potentials for Borehole USW NRG-6

Model Layer	Depth (m)	Measured $-\log(P_c)^*$	Standard Deviation	Optimized $-\log(P_c)$ values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	16.50	5.23040	0.3	5.72160	5.67900	5.66410	5.63290
tcwM2	32.70	5.23040	0.3	5.56550	5.50440	5.48560	5.45230
ptnM4	51.10	5.30100	0.2	5.28090	5.17010	5.14600	5.11210
ptnM5	55.30	5.30100	0.2	5.45200	5.38410	5.30860	5.29330
tswM2	89.00	5.11390	0.5	5.56730	5.50630	5.06510	4.90180
tswM2	105.50	5.14610	0.4	5.53520	5.45810	5.06930	4.89120
tswM3	138.90	5.00000	0.9	5.38890	5.33820	5.37700	5.02210
tswM3	156.20	5.00000	1.0	5.38960	5.33800	5.36900	5.01410

* P_c = capillary pressure (Pa).

Table 24. Measured and Simulated Matrix Water Potentials for Borehole UE-25 UZ#4

Model Layer	Depth (m)	Measured $-\log(P_c)^*$	Standard Deviation	Optimized $-\log(P_c)$ values for Different Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	14.50	5.11390	0.4	5.55350	5.45730	5.40560	5.35910
ptnM1	26.00	4.44720	0.7	5.38850	5.24010	5.15330	5.07300
ptnM2	35.80	5.23040	0.3	5.24280	5.17220	5.14870	5.12150
ptnM4	46.50	5.20410	0.3	5.11440	5.01000	4.96580	4.93000
ptnM5	55.10	5.36170	0.2	5.45260	5.48780	5.34840	5.29570
ptnM5	89.90	5.25530	0.3	5.33360	5.17900	5.06520	5.09710
tswM1	105.30	5.07920	0.5	5.30750	5.13810	5.19100	5.12990
tswM2	115.30	4.89210	0.4	5.55290	5.46000	5.03440	4.86940

* P_c = capillary pressure (Pa).

Table 25. Measured and Simulated Matrix Water Potentials for Borehole USW SD-12

Model Layer	Depth (m)	Measured -log(Pc)*	Standard Deviation	Optimized -log(Pc) values for the Different-Percentile Infiltration Scenarios			
				10th Percentile	30th Percentile	50th Percentile	90th Percentile
tcwM2	30.30	5.91380	0.1	5.76460	5.73030	5.65730	5.53760
tcwM2	47.40	5.51850	0.1	5.62840	5.59810	5.53910	5.43810
tcwM2	64.50	5.23040	0.3	5.42350	5.39330	5.35000	5.28410
tcwM3	75.50	5.11390	0.4	5.20200	5.16070	5.11800	5.08230
ptnM1	78.80	5.11390	0.4	5.10360	5.05110	4.99550	4.94770
ptnM6	90.50	5.17610	0.4	5.04780	4.91430	4.79010	4.86190
tswM2	109.00	4.61280	0.5	5.40030	5.35100	4.99160	4.81630
tswM2	125.10	4.68120	0.5	5.29560	5.25570	5.00020	4.78770
tswM4	211.70	5.23040	0.3	5.11410	5.13510	4.89040	4.70990
tswM4	230.50	5.27880	0.3	5.08190	5.08200	4.87090	4.51610
tswM5	248.40	5.27880	0.3	5.03740	5.03500	4.96110	4.24260
tswM7	384.20	5.17610	0.3	5.31030	5.37610	5.18880	4.99450
tswMv	403.20	4.83250	0.4	5.37130	5.36000	5.20420	5.06980
ch1Mv	409.96	4.83250	0.4	5.36180	5.37010	5.18820	5.04520
ch2Mv	437.40	5.30100	0.2	4.91690	5.32980	5.07620	5.13330

* Pc = capillary pressure (Pa).

1.3 GRAPHICAL PRESENTATION OF PNEUMATIC DATA AND CALIBRATION RESULTS

Figures 1 to 19 show matches between calibrated (dashed lines) and observed (solid lines) pneumatic pressure data for each borehole and the measurement point used in the one-dimensional calibrations of site-scale (mountain-scale) fracture permeability for the four infiltration cases. Model-data comparisons are shown for measurement points in the five boreholes used in the calibration: UE25 NRG#5, USW NRG-6, USW NRG-7A, USW SD-7, and USW SD-12. The pneumatic pressure plot for the 10th percentile infiltration case at USW SD-12 is presented in *Calibrated Unsaturated Zone Properties* (SNL 2007a, Figure 6-9). In the figures that follow, simulated and observed pressure curves are shifted along the vertical axis for some model layers, as indicated, to better display the results. The measurement point elevation (in meters) and corresponding hydrologic model layer are also given. Note that pneumatic pressure signals corresponding to the Tiva Canyon welded (TCw) unit are almost identical to the top boundary condition for the given borehole because there was little pressure attenuation in the TCw unit. Details of the calibration are provided in *Calibrated Unsaturated Zone Properties* (SNL 2007a, Section 6.3.3 and Appendix E). The data used to plot these figures are from DTNs: LB0611MTSCHP10.001, LB0611MTSCHP30.001, LB0612MTSCHP50.001, and LB0612MTSCHP90.001 for the 10th, 30th, 50th, and 90th percentile infiltration cases, respectively. The three-dimensional calibration with pneumatic pressure data is described in *UZ Flow Models and Submodels* (SNL 2007b, Section 6.4). The differences between the data and the model are generally much less than the range of temporal pressure variability. The model is able to follow in all cases the general pattern of lower-frequency pressure variations caused by changes in surface pressure. Differences between the modeled and measured pressures are caused by grid discretization effects, three-dimensional effects, fracture permeability variability within model layers, and differences between modeled and existing water saturations.

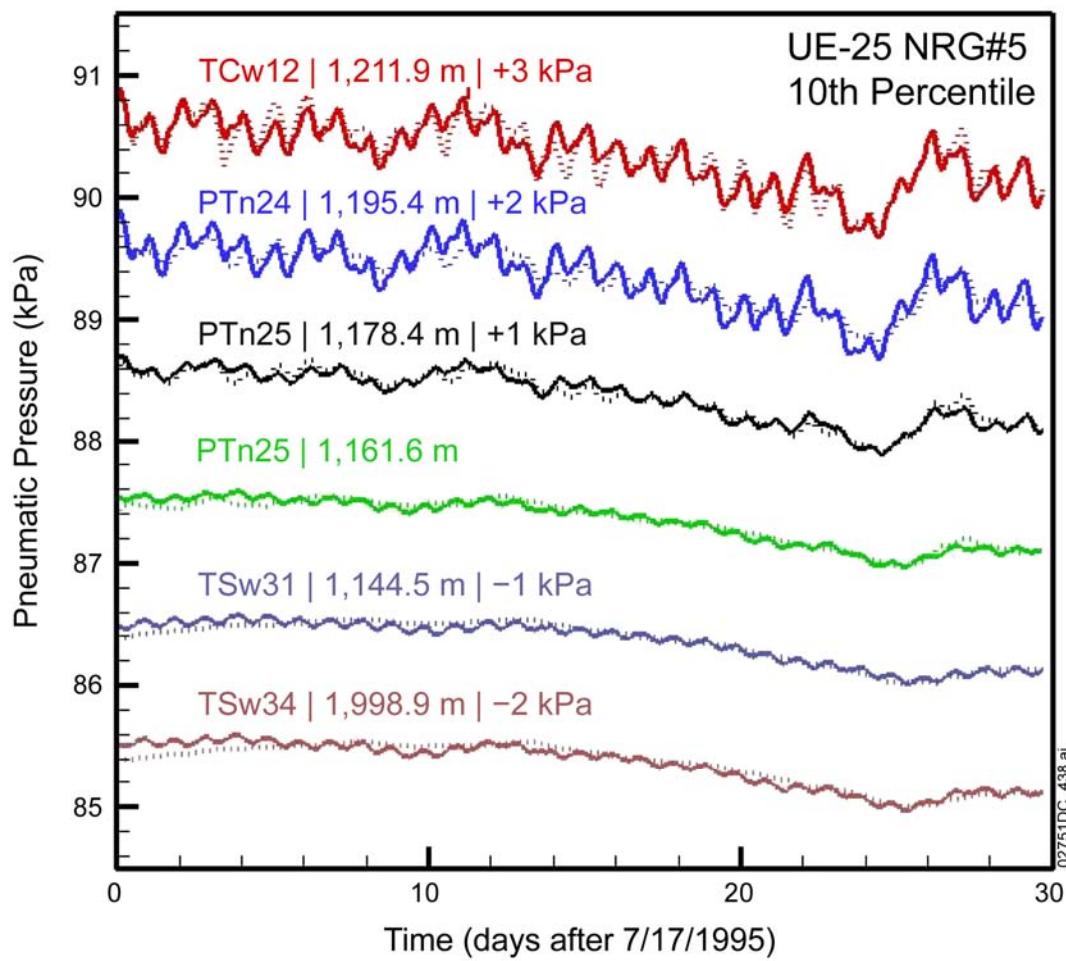


Figure 1. Pneumatic Pressure Matches at UE-25 NRG#5 for the 10th Percentile Infiltration Scenario

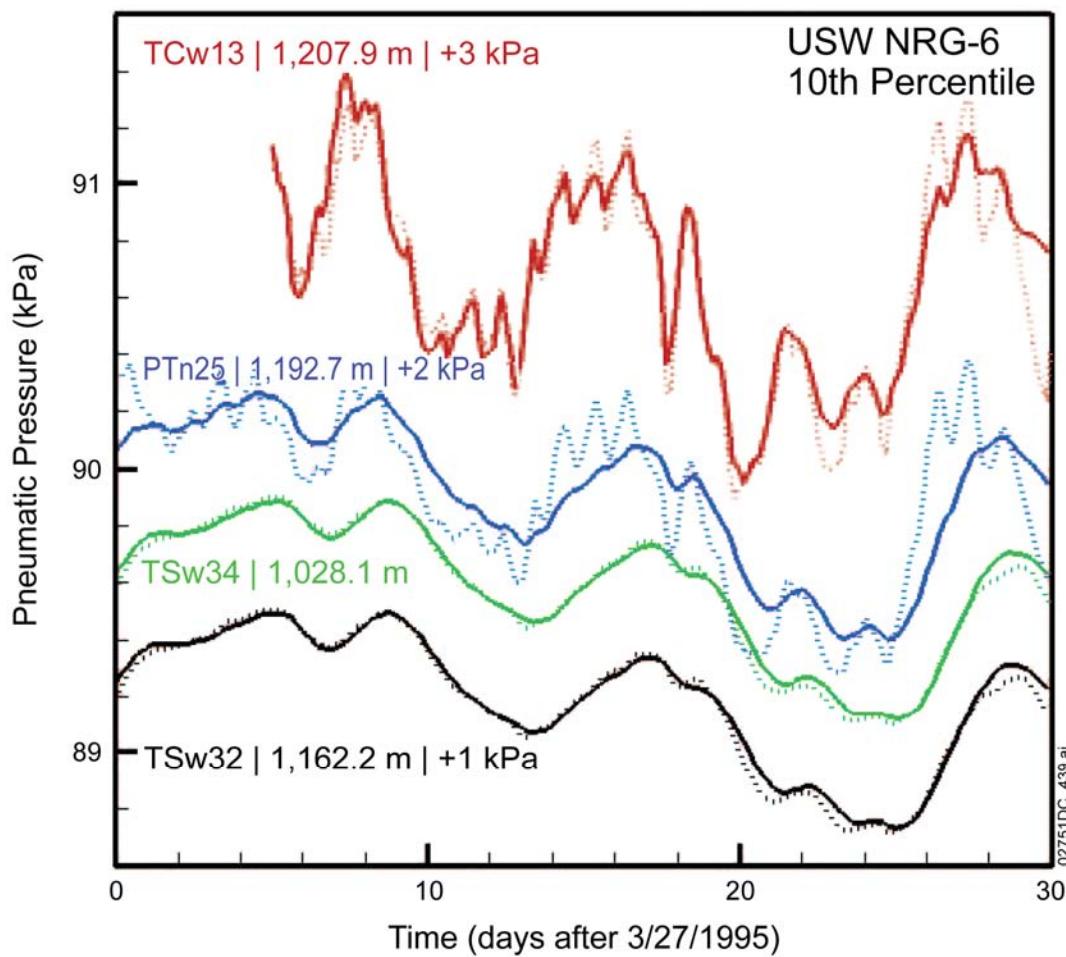


Figure 2. Pneumatic Pressure Matches at USW NRG-6 for the 10th Percentile Infiltration Scenario

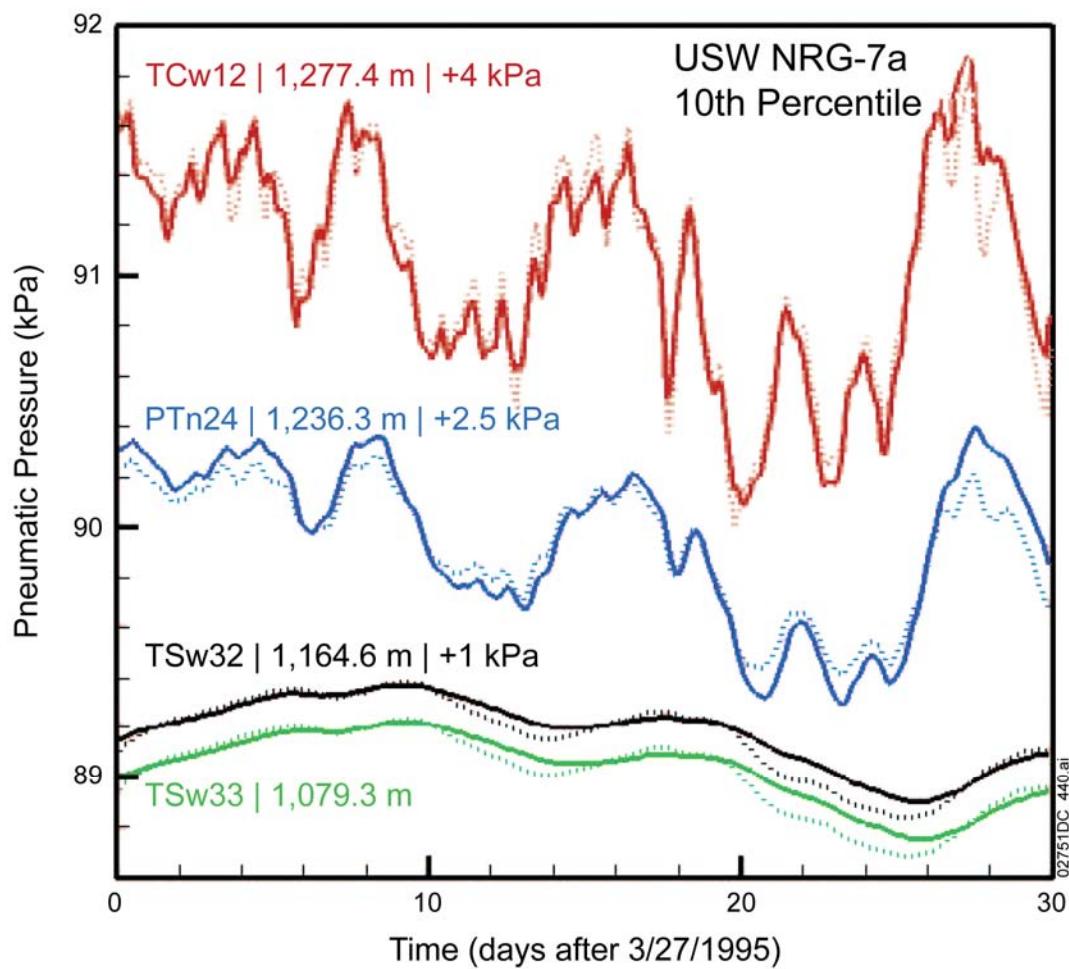


Figure 3. Pneumatic Pressure Matches at USW NRG-7a for the 10th Percentile Infiltration Scenario

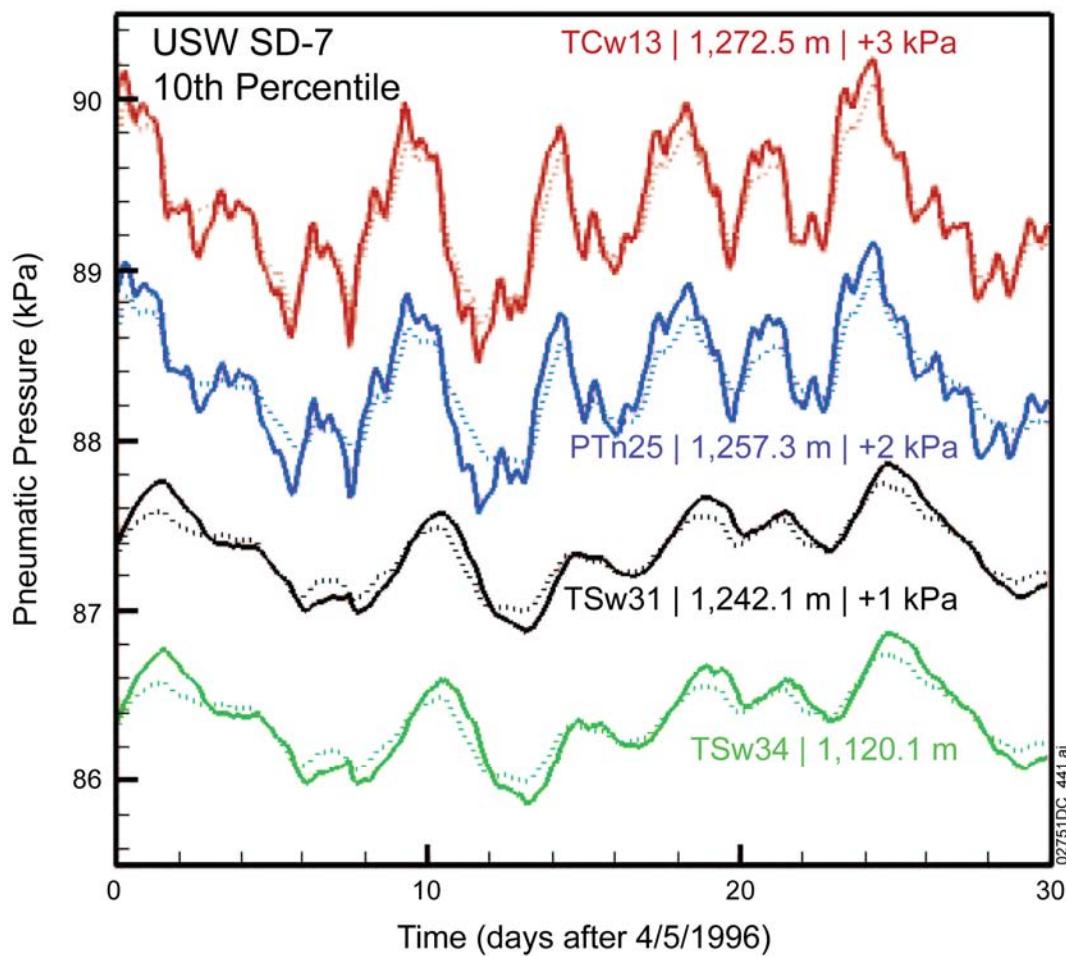


Figure 4. Pneumatic Pressure Matches at USW SD-7 for the 10th Percentile Infiltration Scenario

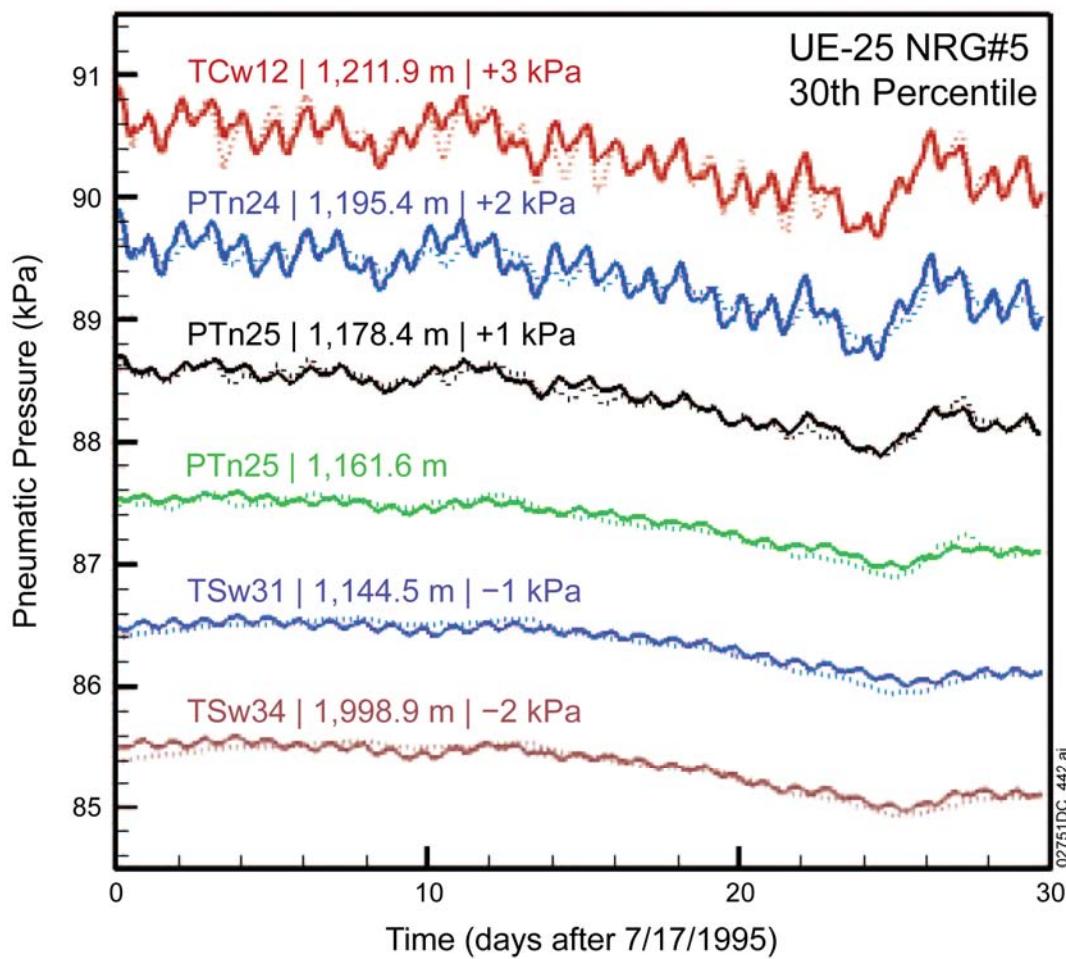


Figure 5. Pneumatic Pressure Matches at UE-25 NRG#5 for the 30th Percentile Infiltration Scenario

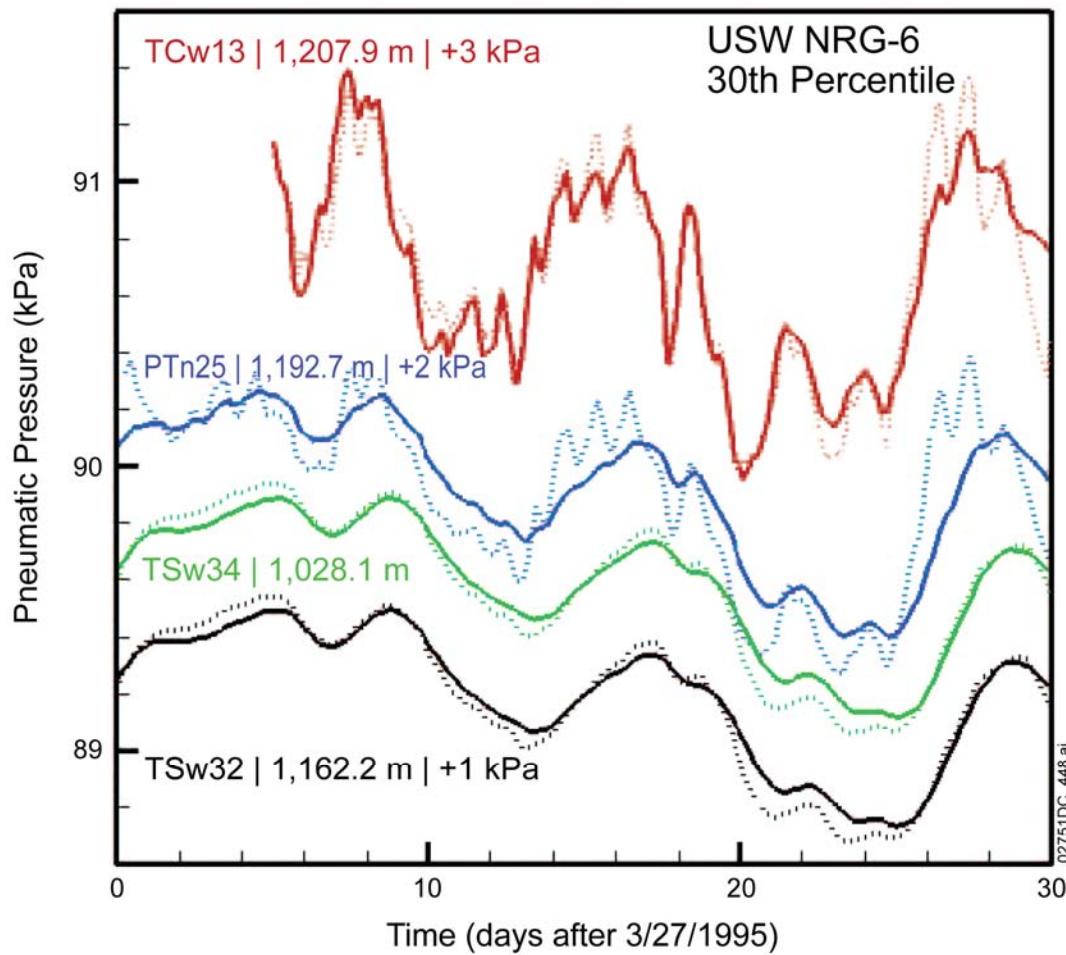


Figure 6. Pneumatic Pressure Matches at USW NRG-6 for the 30th Percentile Infiltration Scenario

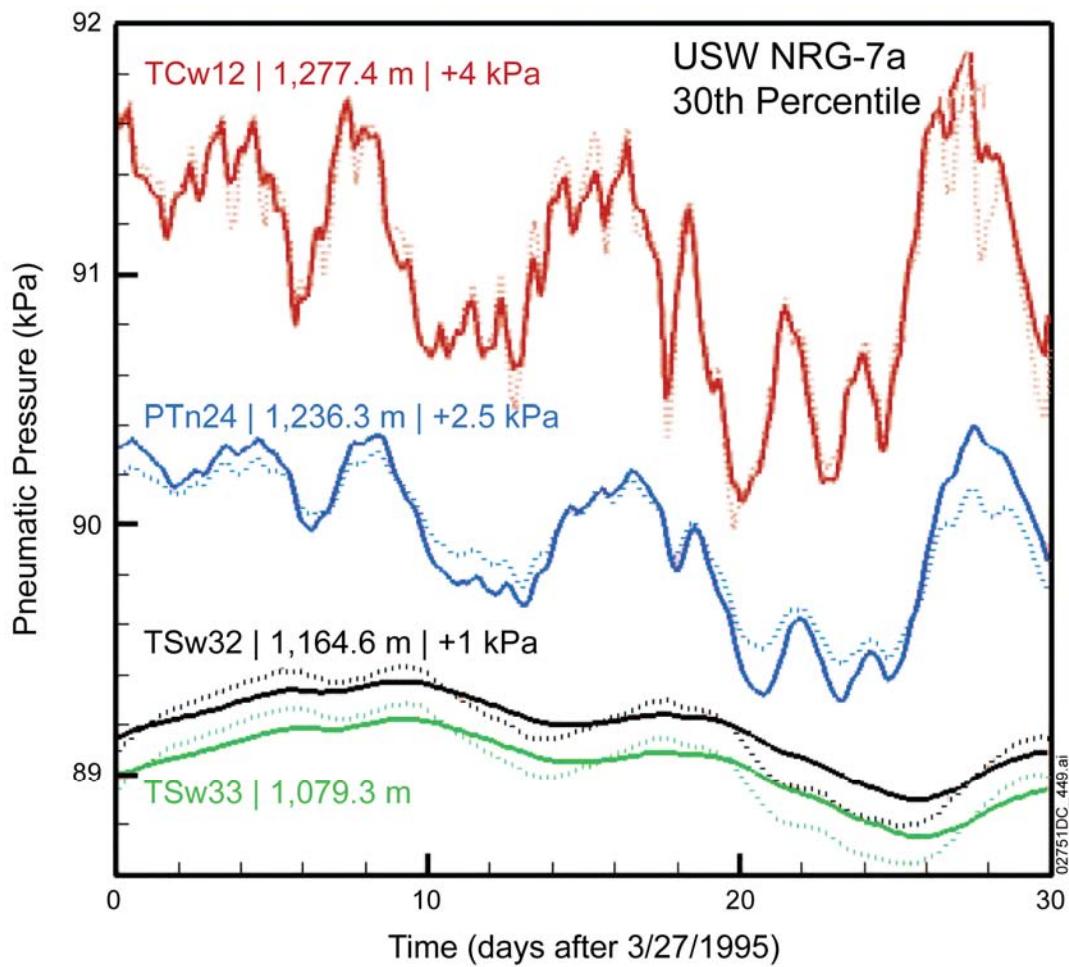


Figure 7. Pneumatic Pressure Matches at USW NRG-7a for the 30th Percentile Infiltration Scenario

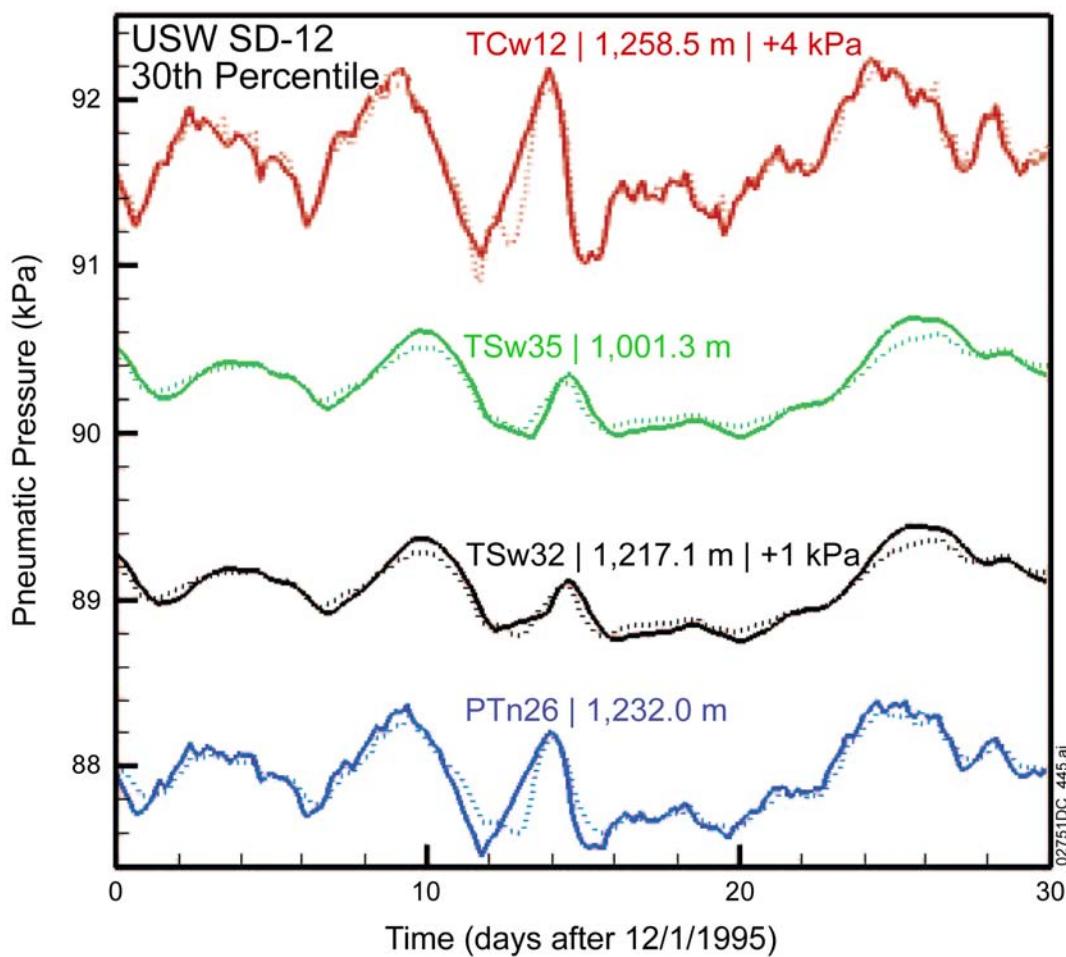


Figure 8. Pneumatic Pressure Matches at USW SD-12 for the 30th Percentile Infiltration Scenario

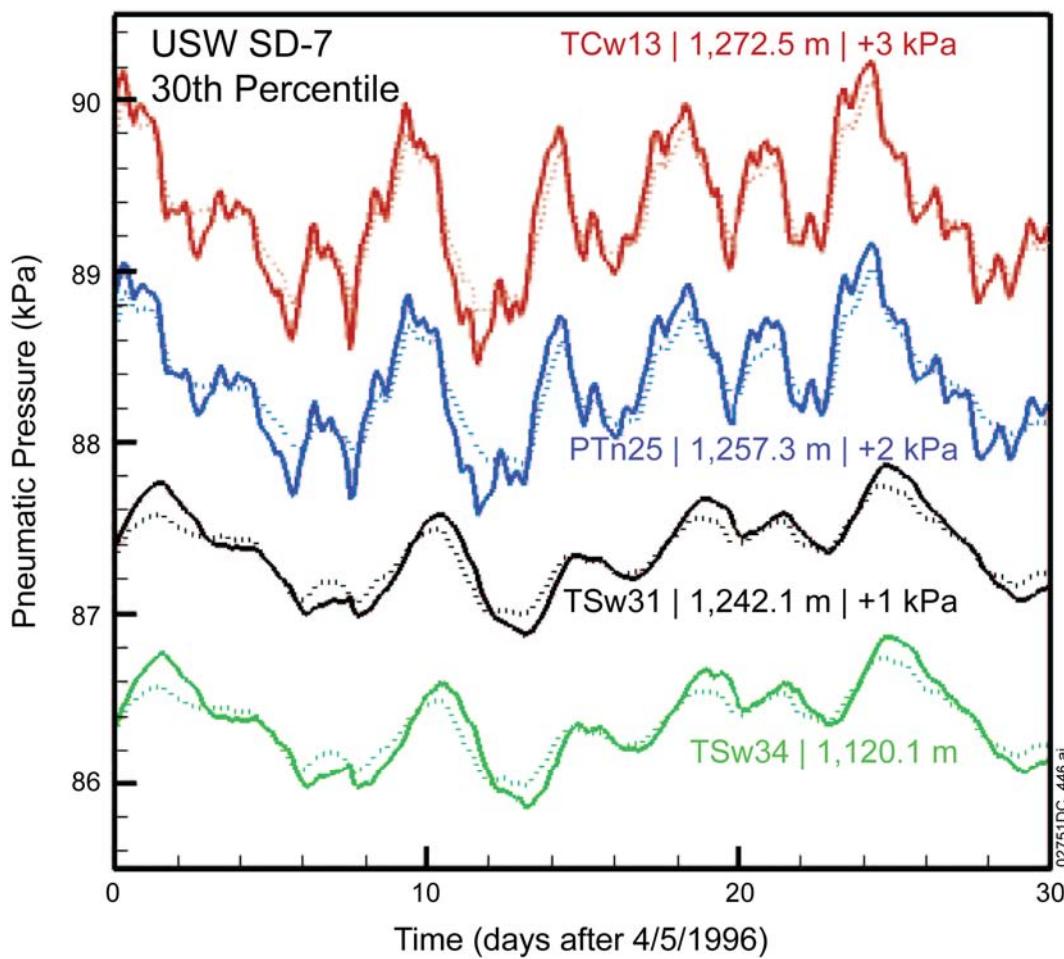


Figure 9. Pneumatic Pressure Matches at USW SD-7 for the 30th Percentile Infiltration Scenario

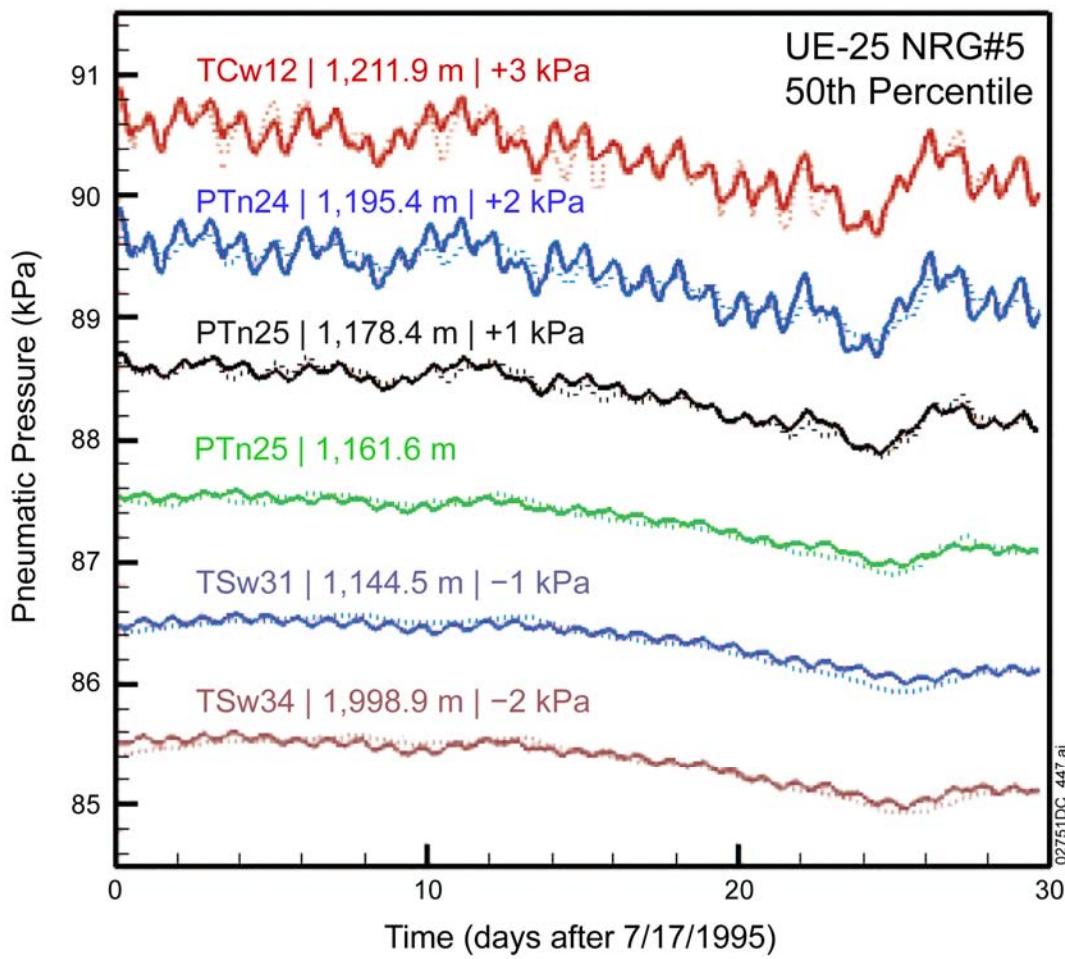


Figure 10. Pneumatic Pressure Matches at UE-25 NRG#5 for the 50th Percentile Infiltration Scenario

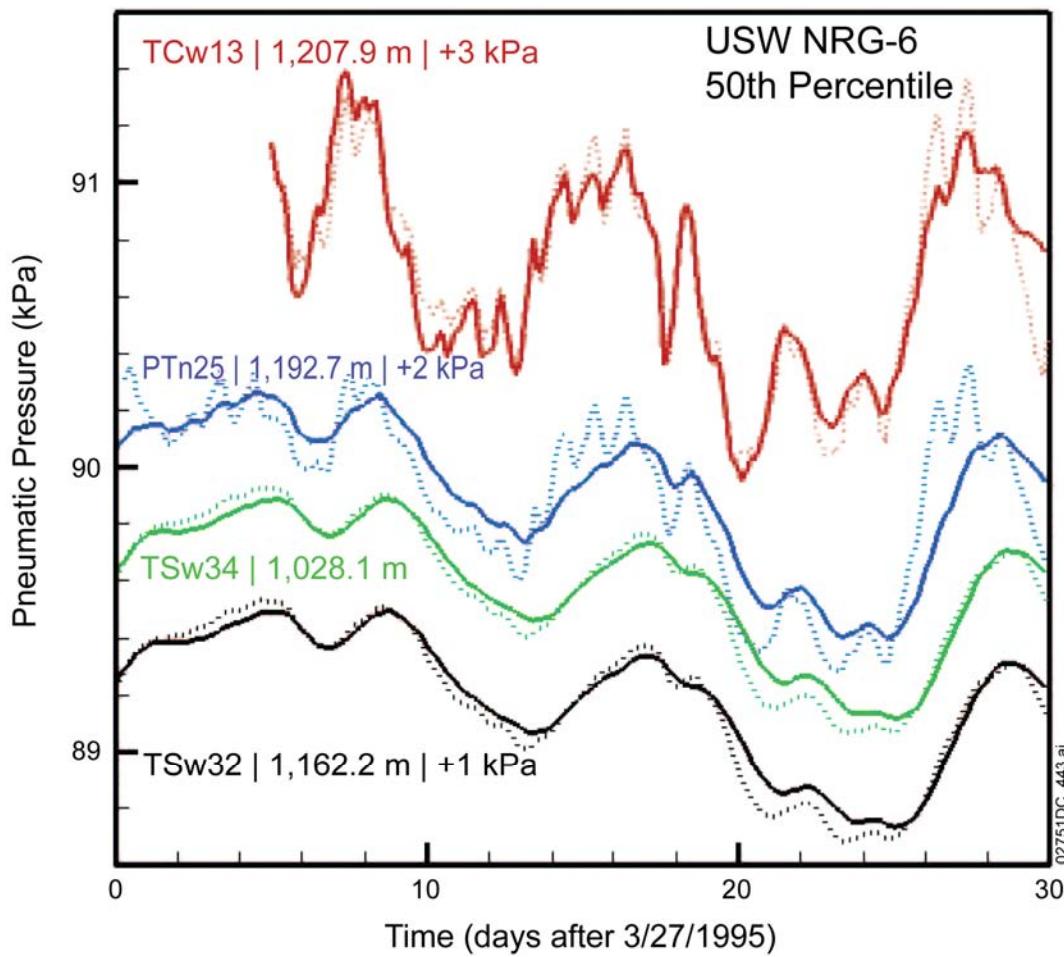


Figure 11. Pneumatic Pressure Matches at USW NRG-6 for the 50th Percentile Infiltration Scenario

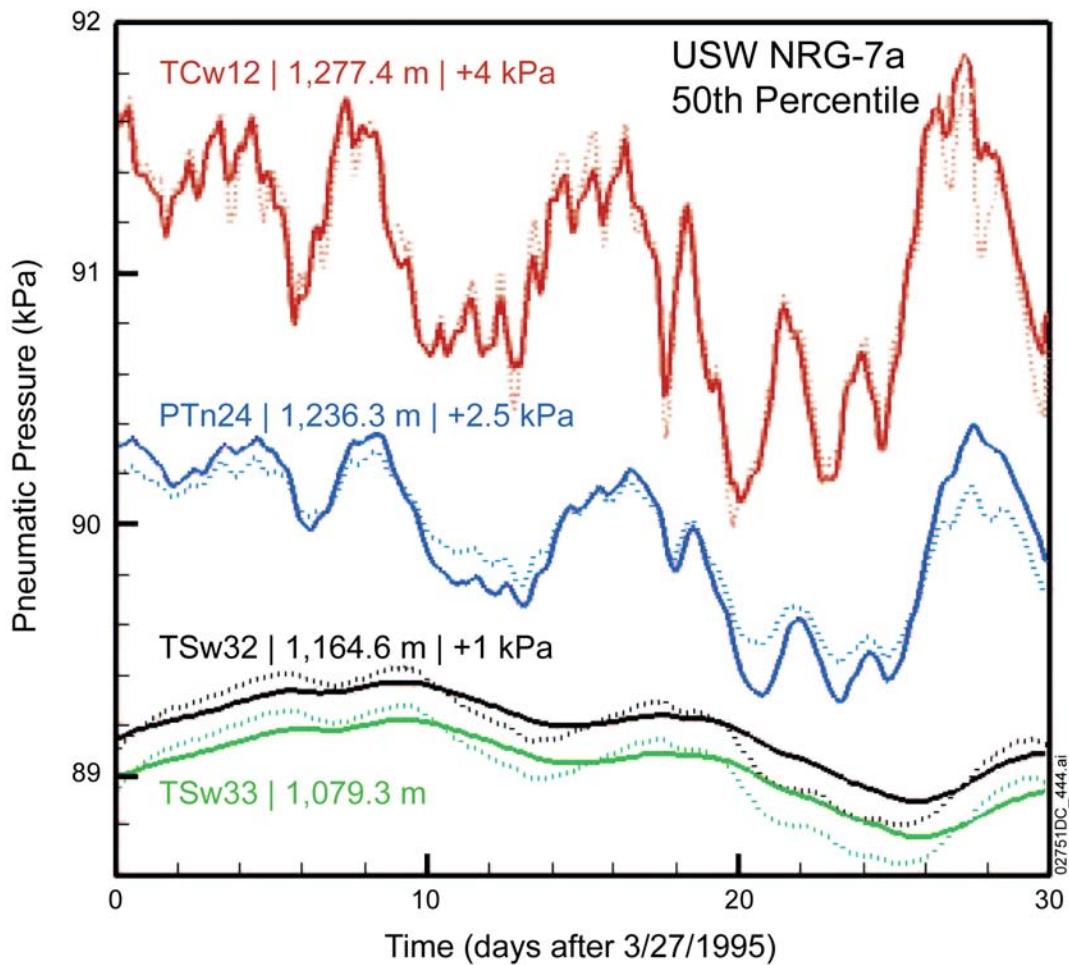


Figure 12. Pneumatic Pressure Matches at USW NRG-7a for the 50th Percentile Infiltration Scenario

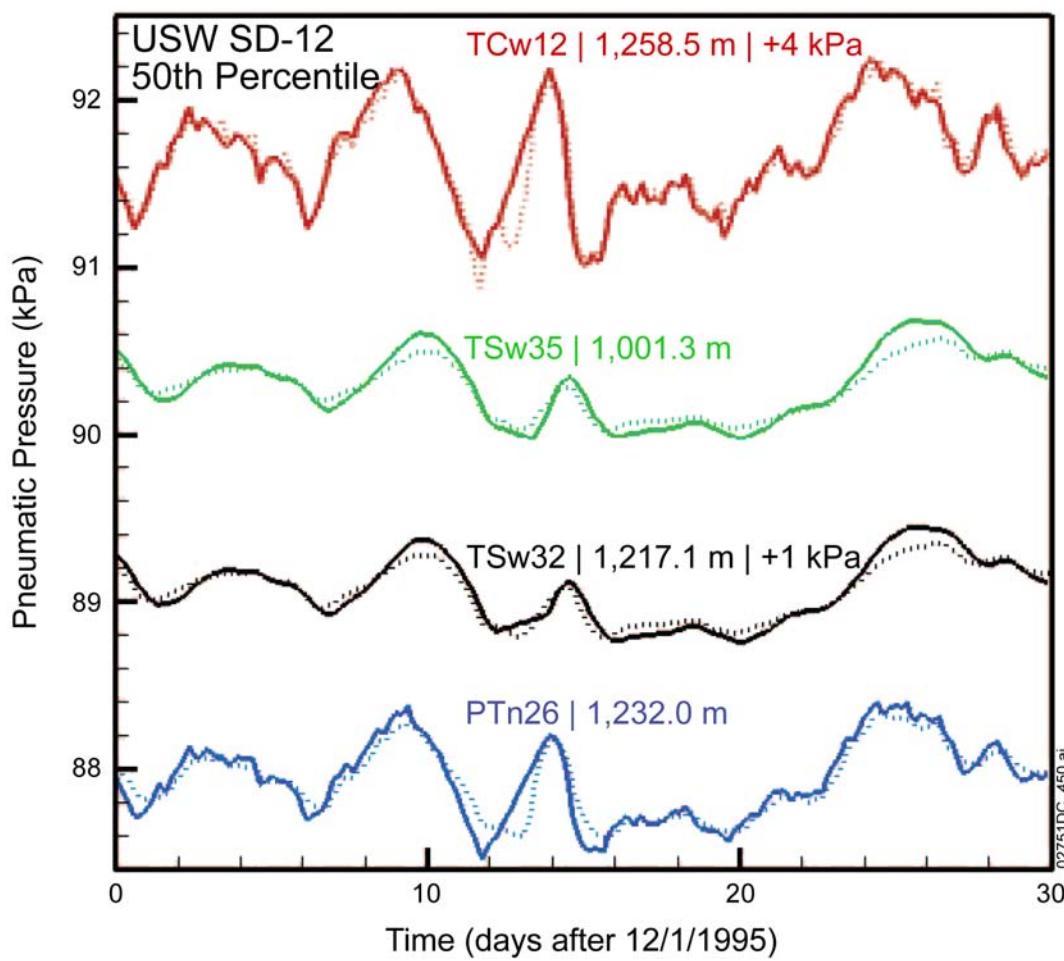


Figure 13. Pneumatic Pressure Matches at USW SD-12 for the 50th Percentile Infiltration Scenario

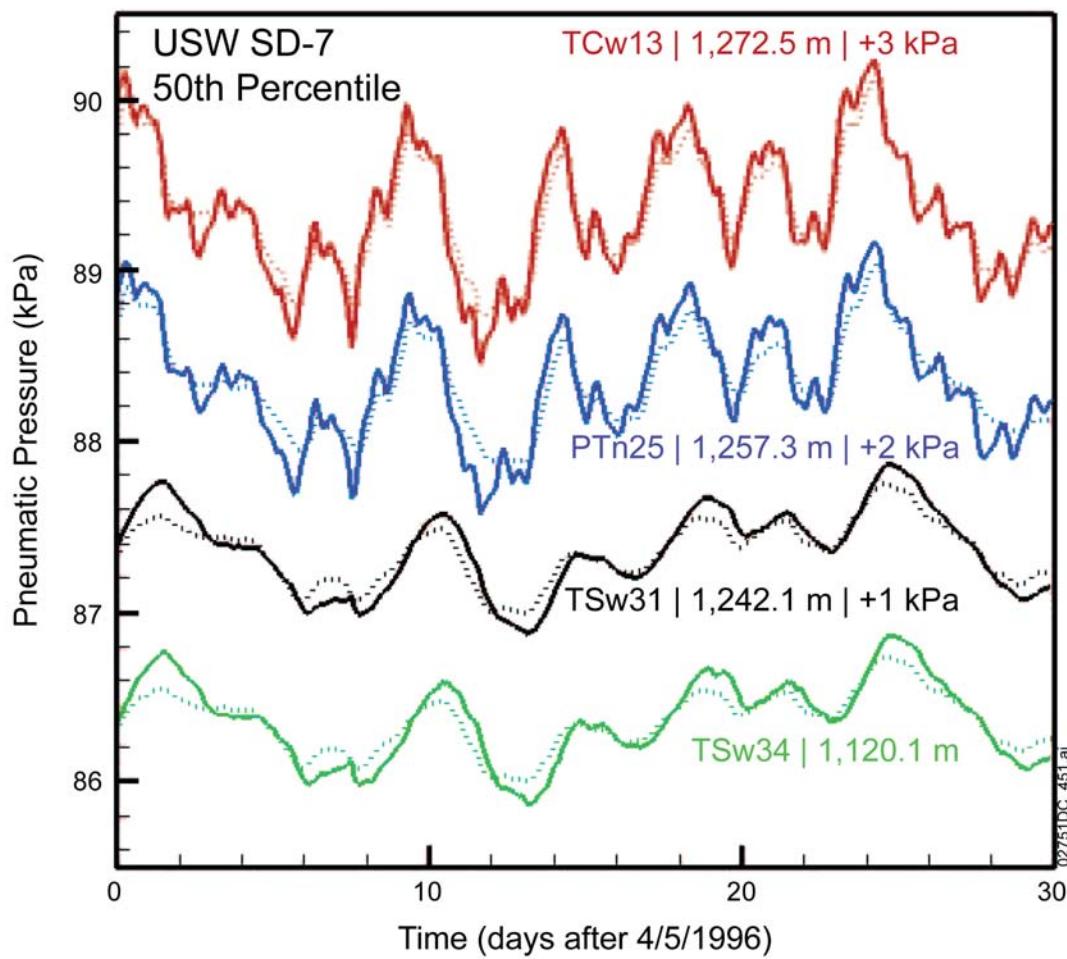


Figure 14. Pneumatic Pressure Matches at USW SD-7 for the 50th Percentile Infiltration Scenario

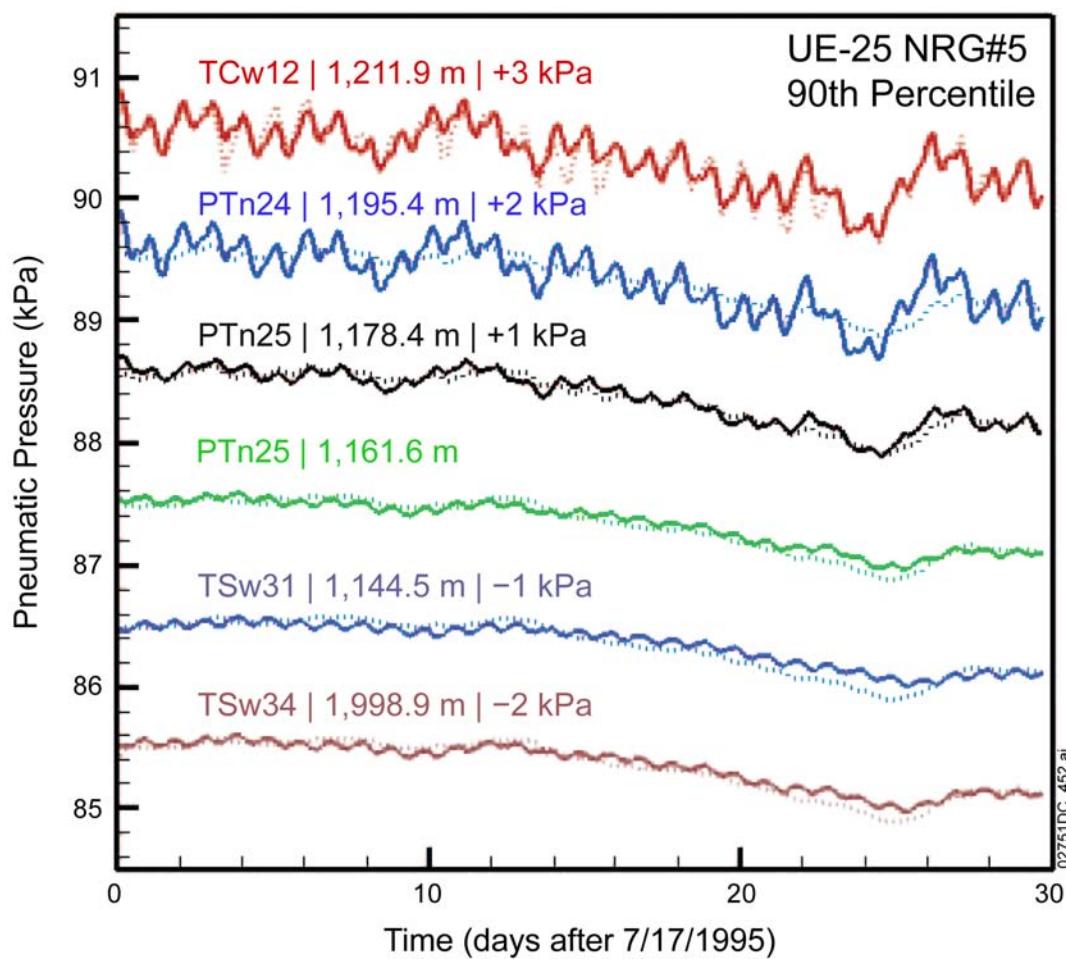


Figure 15. Pneumatic Pressure Matches at UE-25 NRG#5 for the 90th Percentile Infiltration Scenario

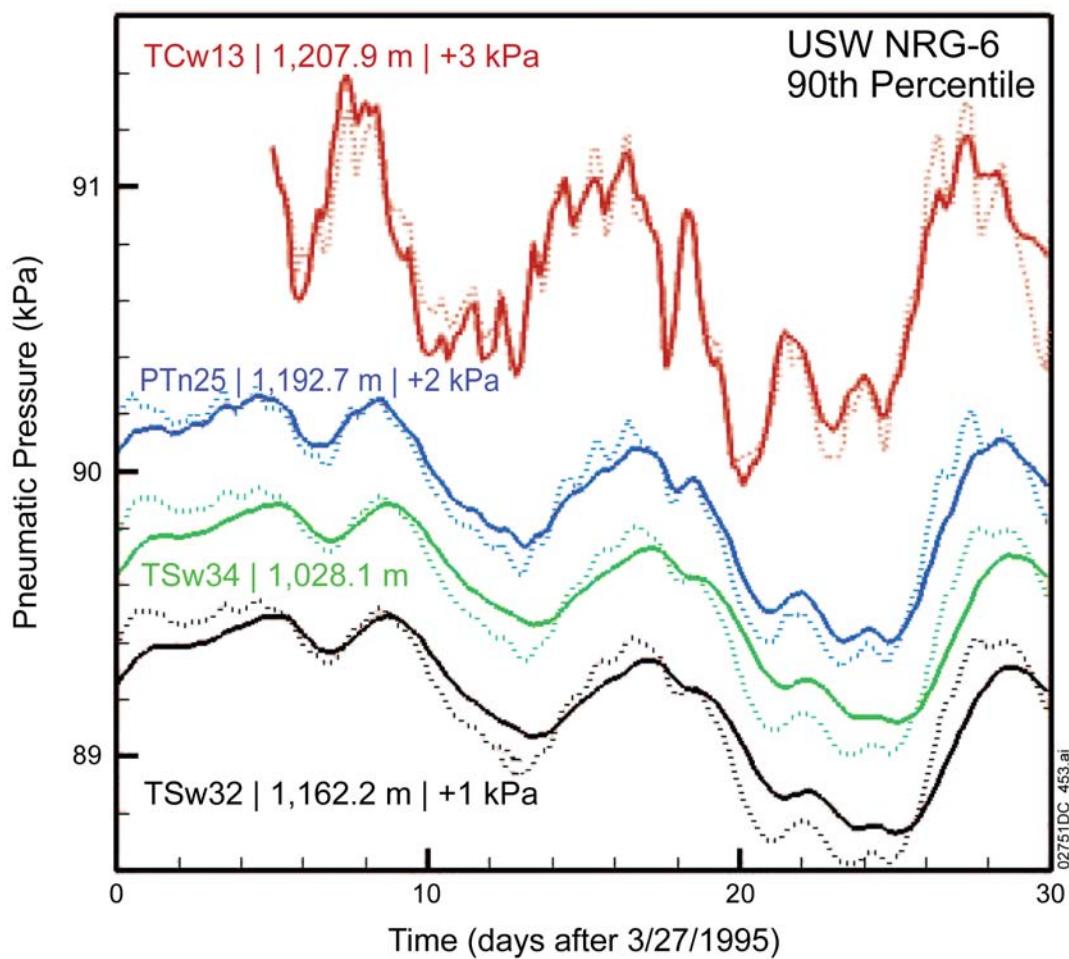


Figure 16. Pneumatic Pressure Matches at USW NRG-6 for the 90th Percentile Infiltration Scenario

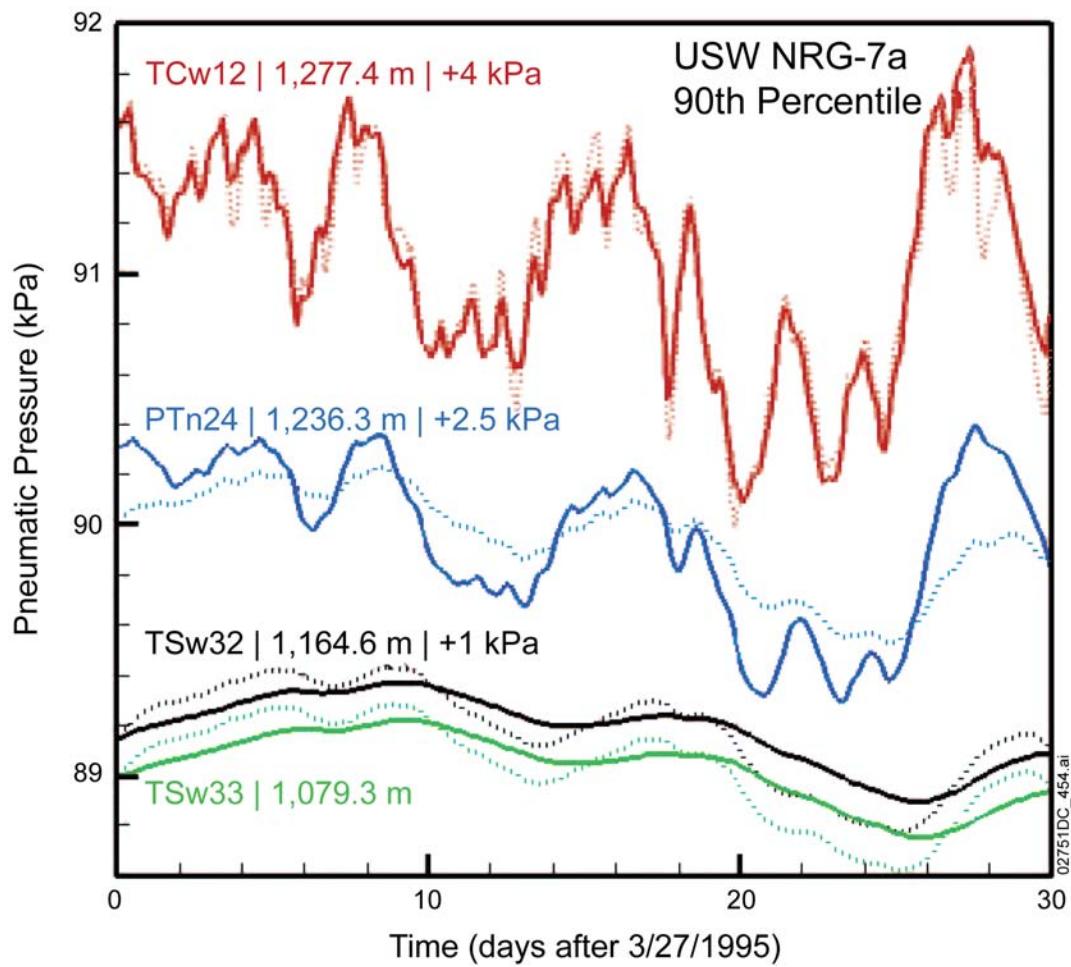


Figure 17. Pneumatic Pressure Matches at USW NRG-7a for the 90th Percentile Infiltration Scenario

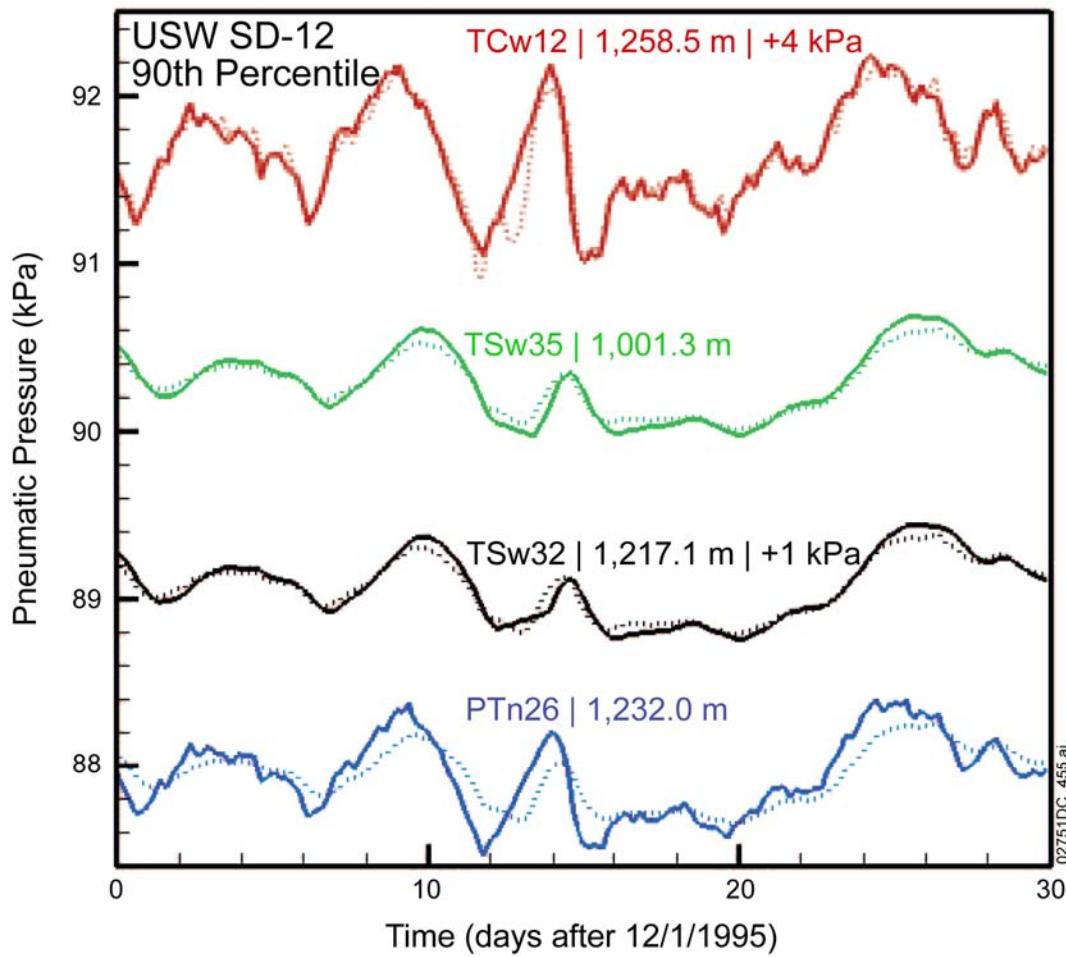


Figure 18. Pneumatic Pressure Matches at USW SD-12 for the 90th Percentile Infiltration Scenario

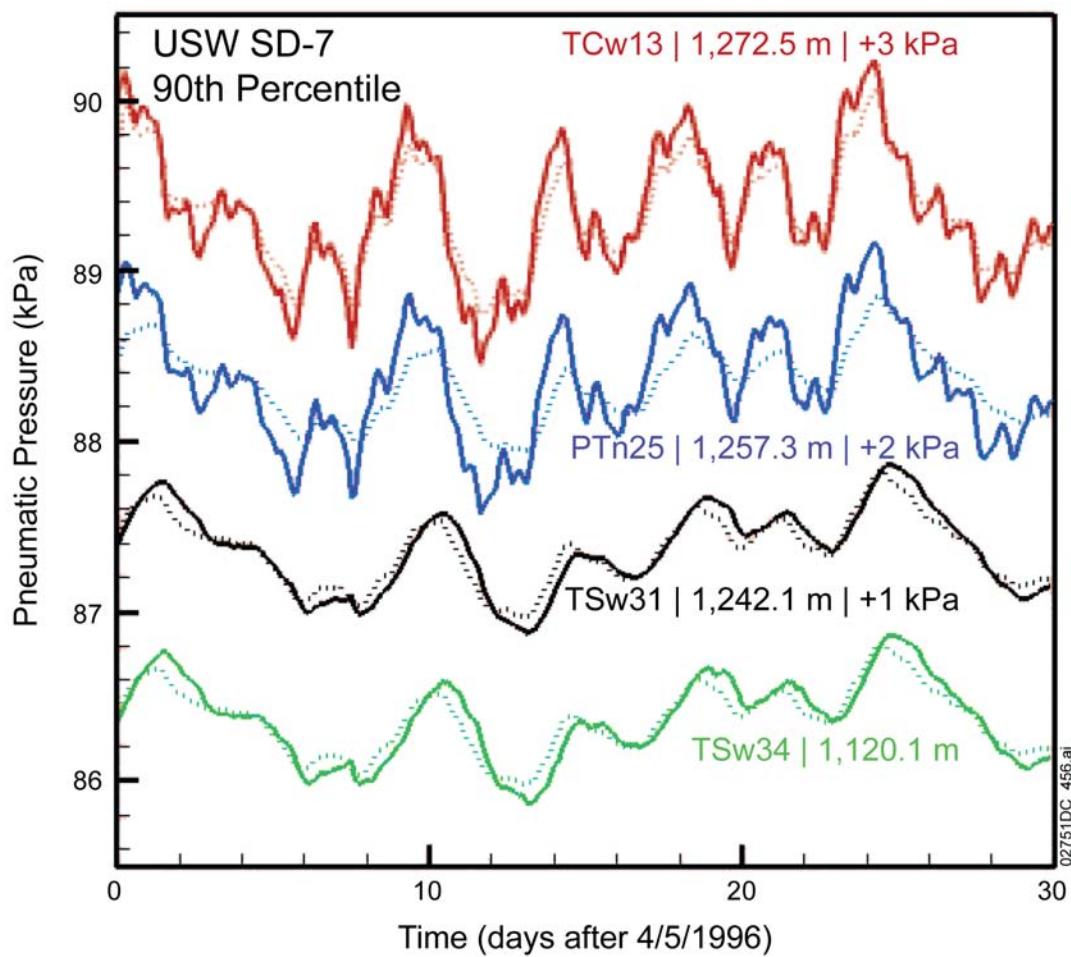


Figure 19. Pneumatic Pressure Matches at USW SD-7 for the 90th Percentile Infiltration Scenario

1.4 ADDITIONAL INFORMATION ON DATA USED FOR CALIBRATIONS

Example plots of measured data supporting the aggregated matrix saturation values used as input to the one-dimensional calibrations for boreholes USW SD-9, USW SD-12, and USW UZ-14 are shown in Figures 20 to 22, respectively. The uncertainty bars on these plots represent the standard deviations used as input to the calibration. Examination of these figures and Tables 2 to 21, shows that the available data provide sufficient coverage of hydrogeologic units and the finer-scale hydrologic model units as well. Intra-unit trends are represented in the calibration because the aggregated values capture trends in the data values (Figures 20 to 22). For thin model units, the measured matrix saturation data are too sparse to capture intra-unit depth trends. However, such trends, if they existed, would be at scales too small to be represented explicitly in the unsaturated zone model. The unsaturated zone model grid was designed with finer grid spacing at or near geologic contacts where stratigraphic variability is strongest, appropriately emphasizing unit-to-unit variability to represent hydrostratigraphy.

Tables 2 to 21 show that the near-surface units have the greatest number of aggregated constraint values for matrix saturation in the one-dimensional calibration. The Paintbrush Tuff nonwelded (PTn) unit and the Topopah Spring welded (TSw) unit each have more than 100 values. Fewer matrix saturation constraint data were used for the Calico Hills nonwelded (CHn) unit below the repository horizon because of the distribution of depths for the available boreholes. The lower units are represented (for example, in USW SD-12; Figure 21) at sufficient resolution to support unsaturated zone flow and transport models. The lower units are further described in the mountain-scale and three-dimensional calibrations (SNL 2007a, Section 6.3.3).

Constraint data for *in situ* water potential are more sparse because of the availability of instrumented borehole intervals. These data support calibration of hydrologic unit properties at finer scales when combined with the constraining matrix saturation and pneumatic data. Water potential in the unsaturated zone is considered to be more spatially uniform than measurements, such as matrix saturation, which are affected by small-scale variability in rock properties as well as by variability in sample handling. Also, equilibrating flow processes occur *in situ*. Accordingly, intra-unit trends for water potential are assumed to be insignificant, water potential differences between units are limited, and fewer measurements of *in situ* water potential are needed to constrain the hydrologic unit properties.

The following additional information responds to the NRC staff clarification call requesting an evaluation of: (1) whether intra-unit trends in the spatial distributions of measurement are captured in the inversions; (2) whether strong and apparently random variation could impact confidence in the calibration; and (3) whether sparse data coverage of certain units affects confidence in the calibrated property sets. The representation of possible intra-unit trends in matrix saturation and *in situ* water potential is sufficient as discussed above. Random variation is evident in the matrix saturation measurements (Figures 20 to 22), and may be evident in comparisons of *in situ* water potential measurements (SNL 2007a, Appendix A). The uncertainties associated with each constraining data value are specified as inputs to the calibration (Tables 2 to 25). Moreover, these uncertainties are relatively small (i.e., coefficients of variation are generally much less than 1). Hence, the apparently random variation in the

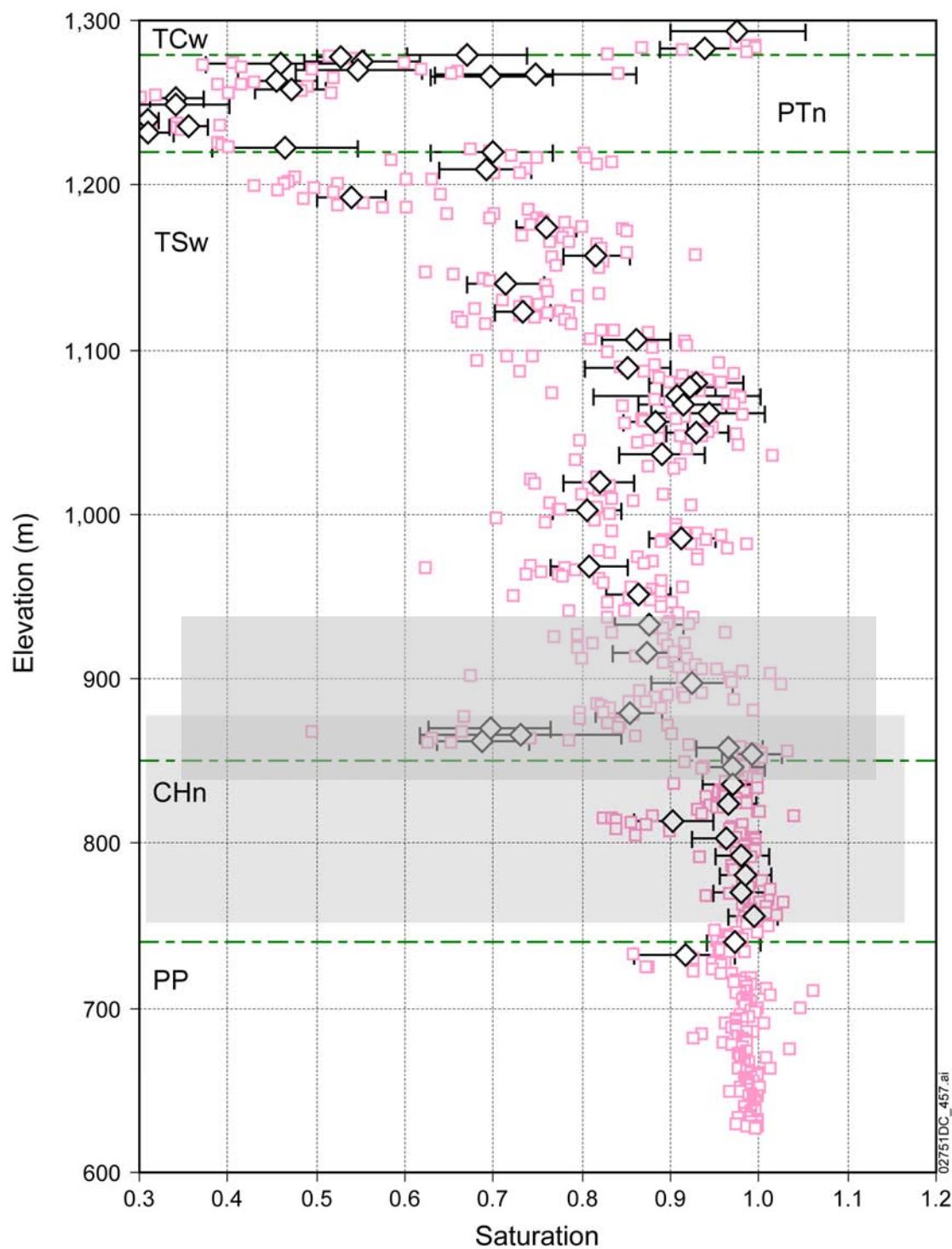
constraining data, as represented in the calibration inputs, does not heavily influence the calibration results.

Sparse data coverage is potentially important for the thinner hydrologic model units and for *in situ* water potential measurements. The calibration model uses carefully evaluated prior information, which includes lithologic similarities and differences among stratigraphic units. This prior information tends to more heavily influence the calibration results where constraining data are not available, so the property values developed for sparsely covered intervals have the benefit of additional information (e.g., lithostratigraphy) from site characterization. Checking of property values that result from calibration (comparison of SAR Tables 2.3.2-3 and 2.3.2-4, and Tables 2.3.2-8 to 2.3.2-11) shows that the resulting solutions are internally consistent and hydrogeologically reasonable.

As mentioned above, matrix saturation data for certain units within the zeolitic portion of the CHn sequence, where perched water was observed, were not used for the one-dimensional calibration because these observations are associated with lateral flow. In the three-dimensional calibrations, properties in the zeolitic portion were adjusted to match matrix saturation, *in situ* water potential, and perched water occurrence data (SNL 2007b, Appendix D). Pneumatic data were not available to calibrate fracture permeability for model layers within the lower portion of the TS_w and below (SNL 2007a, Section 6.2.3), so drift-scale fracture permeability values were used in those model layers. A sensitivity study with the site-scale unsaturated zone flow model indicates that the percolation field is not sensitive to this choice of fracture permeability values (SAR Section 2.3.2.4.2.2).

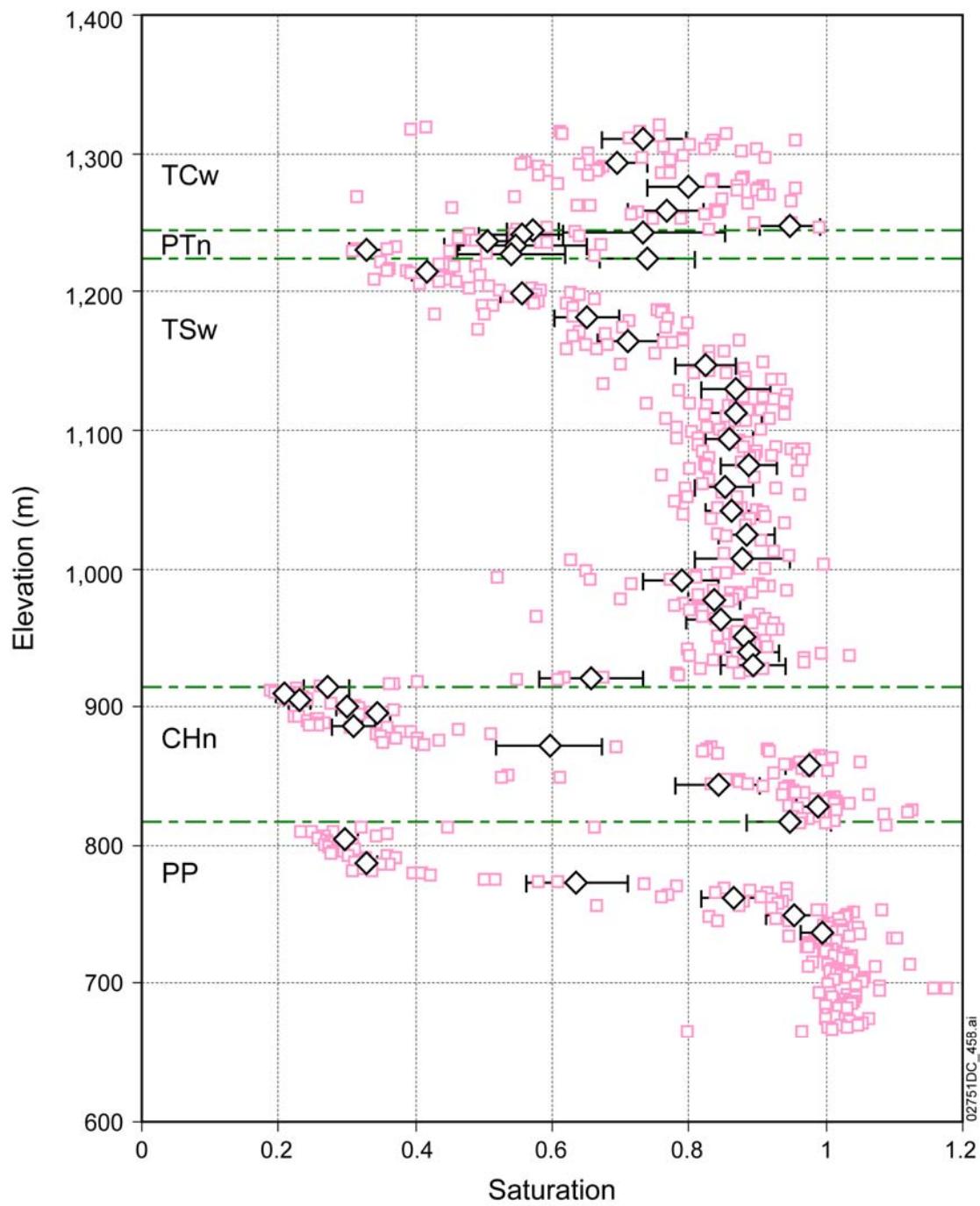
1.5 SUMMARY

In summary, the aggregated matrix saturation and steady-state *in situ* water potential values and uncertainties are representative of the measured data. Pneumatic pressure data were used directly in the calibrations. The three questions raised in the clarification call were addressed in the calibration procedure. Additional support is provided in the calibration report, which summarizes parameter calibrations and uncertainties (SNL 2007a, Section 7.1). The calibrations automatically include adjustments to account for the effects of domain scale on hydrogeologic properties and the joint use of data and the prior information in inversions increases the reliability of the calibrated parameters. The calibration report also provides a summary of the applicable NUREG-1804 acceptance criteria and how these criteria were addressed (SNL 2007a, Section 7.2). Accordingly, the site characterization data and information used in the calibrations and the data manipulation in the calibration procedure are appropriate to support modeling of unsaturated zone flow and transport.



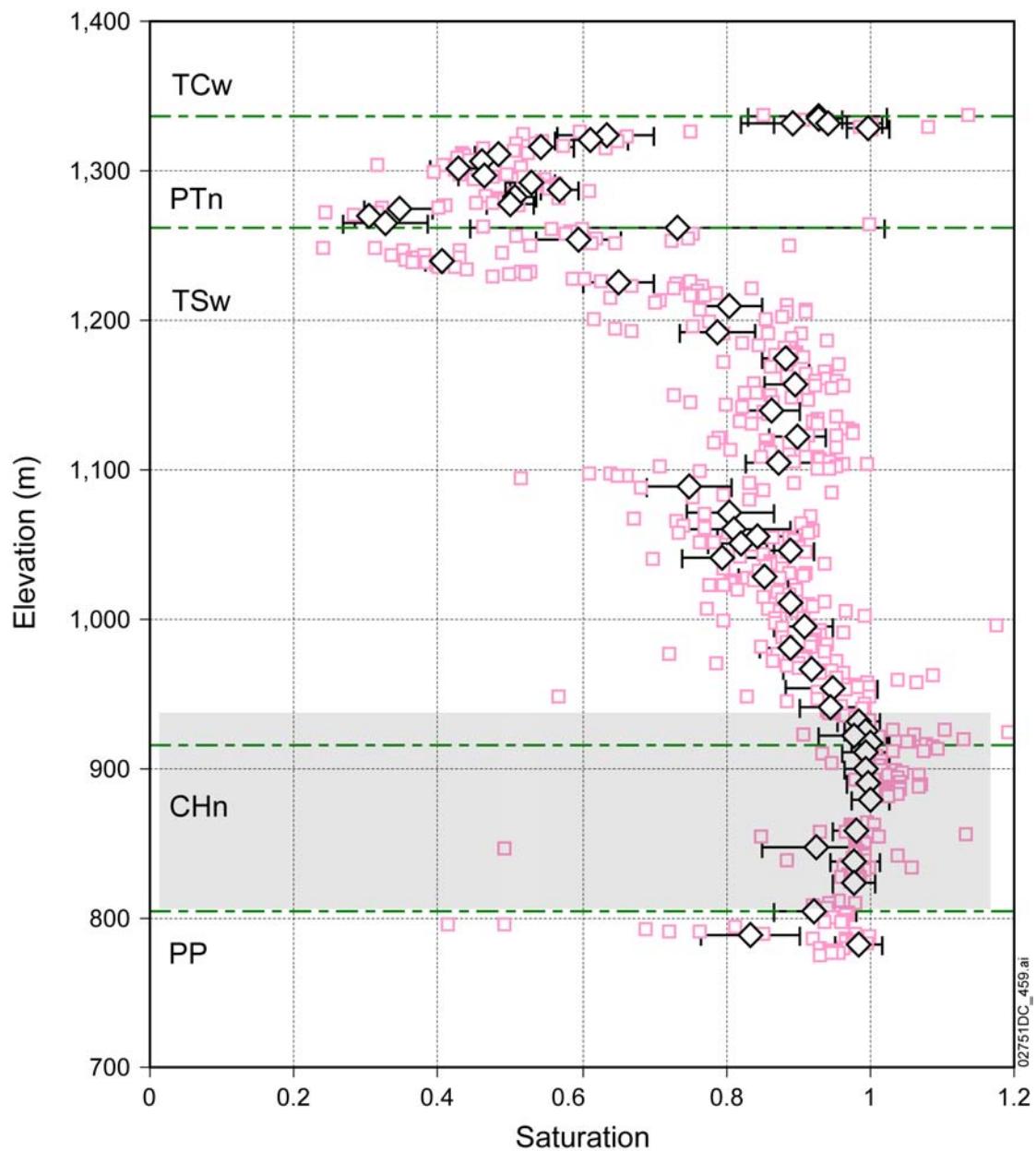
NOTE: Major hydrogeologic units are shown with horizontal dashed lines and labels. Shaded region represents hydrologic model units affected by perching, for which hydrologic properties were obtained from three-dimensional calibration.

Figure 20. Comparison between Core Measurements of Saturation for Borehole USW SD-9 (squares) and Aggregated Values Input for Each Model Grid Block in One-Dimensional Calibration (diamonds)



NOTE: Major hydrogeologic units are shown with horizontal dashed lines and labels.

Figure 21. Comparison between Core Measurements of Saturation for Borehole USW SD-12 (squares) and Aggregated Values Input for Each Model Grid Block in One-Dimensional Calibration (diamonds)



NOTE: Major hydrogeologic units are shown with horizontal dashed lines and labels. Shaded region represents hydrologic model units affected by perching, for which hydrologic properties were obtained from three-dimensional calibration.

Figure 22. Comparison between Core Measurements of Saturation for Borehole USW UZ-14 (squares) and Aggregated Values Input for Each Model Grid Block in One-Dimensional Calibration (diamonds)

2. COMMITMENTS TO NRC

DOE commits to update the LA as described in Section 3. The change will be included in a future LA update.

3. DESCRIPTION OF PROPOSED LA CHANGE

Change SAR Section 2.3.2.4.1.2.3.2 to state that 23 boreholes (instead of 16) were used for one-dimensional calibration of drift-scale properties, and change SAR Section 2.3.2.4.1.2.3.3 to list the five boreholes (instead of two) that were used to calibrate site-scale fracture permeability.

4. REFERENCES

SNL (Sandia National Laboratories) 2007a. *Calibrated Unsaturated Zone Properties*. ANL-NBS-HS-000058 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20070530.0013; DOC.20070713.0005; LLR.20080423.0015; LLR.20080527.0082.

SNL 2007b. *UZ Flow Models and Submodels*. MDL-NBS-HS-000006 REV 03 AD 01. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080108.0003; DOC.20080114.0001; LLR.20080414.0007; LLR.20080414.0033; LLR.20080522.0086.

RAI Volume 3, Chapter 2.2.1.3.6, First Set, Number 9:

Explain the procedure for selecting geochemical observations for the GLUE procedure.

Support the explanation by providing a table (e.g., ASCII file or spreadsheet) describing each geochemical sample for which chloride concentrations were measured and which was obtained during site characterization from those boreholes and drifts that are used in the GLUE procedure, including (as relevant): (i) sample identifier; (ii) borehole or drift identifier; (iii) DTN, (iv) sample type (porewater, perched water, aquifer); (v) date obtained; (vi) depth; (vii) station; (viii) lithographic and hydrology units; (ix) chemical and isotopic composition; (x) Q status; and (xi) a note indicating whether the data is included in GLUE procedure or providing the reason for excluding from the analysis (where applicable). This information is needed to evaluate compliance with 10 CFR 63.114(a), (b), and (c).

Basis: The chloride data used in the GLUE procedure is not clearly traced in the SAR and supporting AMR. Chloride observations displayed in SAR figures 2.3.2-18 through 2.3.2-25, 2.3.2-27, and 2.3.2-28 appear to be inconsistent with the corresponding number of observations identified by SNL (2007, Table 6.5-3) or the set of DTNs within the LSN (including those identified by SNL (2007, Table 6.5-1). Specific examples of chloride discrepancies include:

- There are 60 ECRB and 49 ESF chloride concentrations reported in DTNs identified by DN2002418952 and LA0002JF12213U.002, but the SNL (2007) Table 6.5-3 reports 26 and 31 values and Figures 6.5-4 and 6.5-5 report 23 and more than 70 values, respectively;
- SNL (2007) Table 6.5-3 ascribes 6 chloride concentration values to borehole UZ-N55 but there are only 3 unique values in the DTNs reported in Table 6.5-1;
- Table 6.5-3 reports 10 chloride concentration values for borehole SD-7 but there are 37 values identified by DN2002418952 and LAJF831222AQ98.011; and
- Table 6.5-3 reports 3 chloride concentration values for borehole SD-7 but there are 38 values identified by DN2002418952.

The number of samples identified from the LSN matched for boreholes G-2 and UZ-7a, Table 6.5-3 identified more samples than were found in the LSN for NRG-6, SD-12, UZ-14, and UZ-N55, and more samples were identified in the LSN than cited in Table 6.5-3 for the remaining 6 boreholes, the ESF, and the ECRB.

1. RESPONSE

Chloride was chosen for use in the generalized likelihood uncertainty estimation (GLUE) analysis because: (1) the source term is relatively well constrained; (2) chloride does not participate significantly in chemical reactions in the unsaturated zone environment; and (3) chloride is well-known in scientific literature as a natural aqueous species suitable for quantitative evaluations of infiltration and percolation flux. Section 1.1 provides a detailed accounting, by location, of the number of chloride measurements used in the GLUE analysis of infiltration uncertainty. Section 1.2 provides data for major-ion pore-water composition in the unsaturated zone, strontium concentration and strontium isotopic composition, and ^{36}Cl concentration relative to locations that were also used for chloride concentration measurements. The requested information on tritium has been provided in response to RAI 3.2.2.1.2.1-5-005. The data are described and evaluated below in terms of their suitability for evaluating infiltration uncertainty. Tables 2 to 9 referred in the sections that follow are given in file *Tables 2-9.xls* provided as Enclosure 03. Each table is contained in a separate worksheet in this file, with each worksheet labeled by table number (e.g., Table 2).

1.1 CHLORIDE DATA USED FOR GLUE ANALYSIS

Qualified chloride measurements used for the GLUE analysis from different surface-based boreholes and drifts are tabulated in Table 1. Sample measurements were taken from 12 surface-based boreholes, the Exploratory Studies Facility (ESF) drift and the Enhanced Characterization of the Repository Block (ECRB) drift. The second column of Table 1 presents the number of independent, qualified chloride measurements from each borehole, the ESF, and the ECRB. The second column of Table 1 accounts for all qualified chloride measurements from boreholes used for the GLUE base-case and sensitivity analyses, including measurements from below the water table. The third column of Table 1 accounts for measurements from the second column obtained from locations below the water table. The six samples from borehole USW G-2 were obtained from its water column after the borehole had been drilled to its final depth. Therefore, these samples cannot be assigned a specific depth and should have been excluded from the unsaturated zone analysis. A comparison of USW G-2 chloride measurements with the chloride model results follows the same trend found at other boreholes (SNL 2007a, Figures 6.5-1 to 6.5-11). Therefore, the effect of excluding the USW G-2 measurements from the GLUE analysis is not significant.

For many boreholes, chloride data were recorded in multiple data tracking number (DTN) files. This results in duplicate values, where a duplicate is defined as a value that is a function of the set of independent measurements. In some cases, the multiple DTN files for a borehole contained the same measurements. The number of duplicate values is shown in the fifth column of Table 1. The table shows 71 duplicates were used in the base-case analysis with 51 from surface-based boreholes. For surface-based borehole duplicates, duplicate pairs were assigned slightly different depths, generally only a few centimeters apart. Some of the ESF duplicates represent values averaged from the set of independent measurements. Chloride measurements having duplicates are not strongly correlated with respect to the magnitude of the chloride concentrations. Therefore, the use of these duplicates will not significantly affect the GLUE analysis of weighting factors.

Table 1, column six, shows the number of chloride measurements that were inadvertently not included in the base-case analysis that supports total system performance assessment (TSPA) dose calculations. A sensitivity analysis in *UZ Flow Models and Submodels* (SNL 2007a, Appendix J) incorporated 139 of the 187 measurements not included in the base-case analysis. The remaining 48 chloride measurements were identified after performing the chloride sensitivity analysis. The effects of 139 additional measurements on the chloride analysis and weighting factors using the GLUE methodology were evaluated (SNL 2007a, Appendix J, Table J-6). The change in weights has only a minor effect because the change in average infiltration rate for the new weights was small in comparison with the uncertainty represented by the standard deviation. Of the 48 remaining chloride measurements, 22 are from surface-based boreholes. These are predominantly from perched water locations where existing measurements were used in the base-case or sensitivity analyses. The additional values would not have a significant effect on the value of chloride concentration used at those locations. The other 26 values not evaluated are from the ESF and ECRB. Of these, one is from the ECRB with a concentration of 97 mg/L, which is relatively high compared with the general trend in the ECRB. In the ESF, eight values are from the Main Drift with an average concentration of 123 mg/L and 17 are from the South Ramp, with an average concentration of 70 mg/L. The values from the Main Drift are high relative to the base-case values, but because these measurements are colocated, only represent one value used in the GLUE analysis. Values from the South Ramp are similar to values used in the base-case analysis. Therefore, the additional 48 chloride measurements would not result in a significant change in the GLUE weighting factor analysis.

The number of measurements used in the base-case analysis is shown in the seventh column of Table 1. With the exception of measurements from borehole USW G-2, this column equals the number of measurements above the water table in column four, plus the number of duplicates used in column five, minus the number of measurements not used in column six. As noted previously, for borehole USW G-2, the five measurements used in the base-case analysis cannot be uniquely associated with a specific depth.

For the GLUE analysis, measurements from the same location were averaged. The number of unique measurement locations in column eight of Table 1 are less than or equal to the number of measurements above the water table in column four. Similarly, the number of unique measurement locations used in the base-case analysis in column nine are less than or equal to the number of measurements used in the base-case analysis in column seven. The “number of samples” in Table 6.5-3 of *UZ Flow Models and Submodels* (SNL 2007a) is the number of independent locations used in the GLUE analysis, as shown in column nine of Table 1. Note the number of ESF samples in Table J-4 of *UZ Flow Models and Submodels* (SNL 2007a) is incorrect and should have been listed as 39 instead of 40.

Tables 2 and 3 contain the qualified, unsaturated zone chloride data, along with other major ion composition data. The second-to-last column in both tables, labeled “Use”, indicates whether the data were used in either the base-case or sensitivity analysis, or unused. Duplicates are indicated in this column of Table 2 for the surface-based boreholes. Duplicates are not presented for the ESF in Table 3 because these duplicates are not necessarily repeats of any one measurement, but in some cases are averages generated from the measurements given in Table 3. Table 4 presents the values of 20 duplicates used in the ESF base-case analysis.

ENCLOSURE 2

Response Tracking Number: 00341-00-00

RAI: 3.2.2.1.3.6-009

Table 5 presents chloride measurements from the saturated zone in surface-based boreholes used for unsaturated zone chloride measurements. The chloride concentrations in these measurements lie at the lower end of the unsaturated zone measurements. Unqualified chloride data not used in the GLUE base-case or sensitivity analyses are shown in Table 6. Unqualified data were not used because: (1) there are only 17 unqualified measurements in comparison with hundreds of qualified measurements; (2) the values on average are relatively high, leading to lower estimates of infiltration in the GLUE analysis; and (3) the GLUE analysis supports TSPA dose calculations, which requires qualified inputs. Therefore, the exclusion of these data is conservative.

Table 1. Numbers of Chloride Measurements for GLUE Analysis

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Borehole or Drift	Number of Qualified Measurements ^a	Number of Qualified Measurements Below Water Table	Number of Qualified Measurements Above Water Table	Number of Qualified Duplicates Used in Base Case	Number of Qualified Measurements Not Used in Base Case	Number of Qualified Measurements Used in Base Case (including duplicates)	Number of Unique Measurement Locations for Qualified Data	Number of Unique Measurement Locations Used in Base Case (including duplicates) for Qualified Data
USW G-2	6	6	0	0	0	5	0	1
USW NRG-6	9	0	9	4	0	13	7	13
USW NRG-7a	17	0	17	2	6	13	10	10
USW SD-12	14	0	14	3	3	14	14	14
USW SD-6	33	0	33	0	30	3	25	3
USW SD-7	37	5	32	0	5	27	10	10
USW SD-9	47	4	43	1	27	17	42	17
USW UZ-14	83	11	72	21	9	84	46	71
UE-25 UZ#16	53	8	45	17	1	61	28	44
USW WT-24	44	19	25	0	22	3	20	3
UE-25 UZ#7a	3	0	3	0	0	3	3	3
USW UZ-N55	3	0	3	3	0	6	3	6
ESF	126	NA	126	20	53	93	47	31
ECRB	75	NA	75	0	31	44	33	26
Totals	550	53	497	71	187	386	288	252

^a ESF data do not include measurements from the ESF-HD-ChemSamp series of measurements from Alcove 5 because of the potential effects of the drift-scale thermal test on these chloride concentrations.

1.2 CHLORIDE AND OTHER GEOCHEMICAL/ISOTOPIC DATA

Tables 2 to 9 contain the geochemical and isotopic measurements from surface-based and underground boreholes sampled for measurements of chloride concentration. Tables 2 and 3 present pore-water major-ion compositions, including chloride concentrations. As discussed in Section 1.1, Table 4 lists duplicate values used in the GLUE chloride analysis from the ESF, Table 5 presents chloride and other major ion water composition data from the saturated zone, and Table 6 contains unqualified chloride data. Tables 7 and 8 present strontium and strontium isotopic measurements. Table 9 presents ^{36}Cl measurements. Tritium data have been provided in response to RAI 3.2.2.1.2.1-5-005.

In addition to chloride concentration, Tables 2 and 3 present major ion compositions for sampling locations used for chloride measurements. Table 2 contains data for pore-water composition of 302 samples from the surface-based boreholes, and Table 3 contains data for pore-water composition of 202 samples from the ESF and ECRB. A summary of the compositional characteristics of unsaturated zone pore and perched waters is presented in *Yucca Mountain Site Description* (BSC 2004a, Section 5.2.2.4). Table 5 presents 55 groundwater compositions for the saturated zone from boreholes used for chloride measurements. A summary of saturated zone water compositional characteristics is presented in *Yucca Mountain Site Description* (BSC 2004a, Section 5.2.2.7).

Table 7 presents strontium concentration and strontium isotopic measurements taken from six surface-based boreholes used for chloride measurements. Table 8 presents strontium concentration and strontium isotopic measurements taken from the ESF and ECRB at chloride sampling locations. Strontium isotopic data in Tables 6 and 7 are presented as the isotopic ratio $^{87}\text{Sr}/^{86}\text{Sr}$. There are 358 measurements of strontium isotopic ratio and 122 measurements of strontium concentration which are colocated with chloride measurements in surface-based boreholes. The sample type for strontium measurements from surface-based boreholes are mainly rock leachate samples and rock matrix samples, plus a smaller number of perched water samples. Twenty-three measurements of strontium isotopic ratio are colocated with chloride measurements from the ECRB. All ECRB measurements were performed on pore-water samples. Six strontium isotopic measurements, from rock leachate samples, are colocated with ESF chloride measurements. These samples are from Niche 3566, located in a brecciated zone between the Sundance fault and a cooling joint (BSC 2004b, Section 6.1.1.1). Additional information on strontium and strontium isotopes in the unsaturated zone is given in *Yucca Mountain Site Description* (BSC 2004a, Sections 5.2.2.4 and 5.2.2.5).

Although strontium concentrations were not used for the GLUE analysis of infiltration weights, they were used to validate the unsaturated zone flow model (SNL 2007a, Section 7.6). The model treated strontium as a conservative species in non-zeolitic units and as a sorbing species in the zeolitic units. Strontium concentration measurements from surface-based boreholes USW SD-9 and USW SD-12 and the ECRB drift were used in the validation. Most strontium measurements from surface-based boreholes were taken from locations above the zeolitic rock, only present below the repository (SNL 2007a, Figure 7.6-1). All strontium measurements from the ECRB lie above zeolitic rock; therefore, most strontium comparisons shown in Figures 7.6-1 and 7.6-2 of *UZ Flow Models and Submodels* (SNL 2007a) are for strontium transport as a

conservative species and are comparable with chloride comparisons given in Section 6.5 and Appendix J of the same report (SNL 2007a). Results from strontium simulations are similar to results from the chloride simulations in that the 10th and 30th percentile uncertainty cases are consistent with the strontium and chloride data.

Table 9 presents ^{36}Cl measurements from 18 locations that were sampled for aqueous chloride concentration from pore water samples. The ^{36}Cl measurements were taken from Niche 3566 in the ESF. Of this limited data set, 11 of the 18 locations had $^{36}\text{Cl}/\text{Cl}$ ratios greater than $1,250 \times 10^{-15}$, the threshold for the presence of bomb-pulse water (BSC 2006, Section 1).

Strontium was not used in the GLUE analysis because its behavior: (1) is similar to chloride in areas above the zeolites, and (2) in zeolitic rock introduces an additional uncertainty in the parameterization of sorptive interaction with the rock. Strontium isotopic data was not used due to strontium isotopic exchange with the rock. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratio in pore waters is affected along a flow path by dissolution of strontium-bearing phases (e.g., calcite, feldspars, volcanic glass), and exchange with clays or zeolites (SNL 2007a, Section 7.6.1). The ^{36}Cl measurements were not used for the GLUE analysis because of detection and interpretation problems documented in *Chlorine-36 Validation Study at Yucca Mountain, Nevada* (BSC 2006). Additional pore-water chemistry data also suffer from greater uncertainty associated with specification of source term and water-rock interactions. Because of its short half-life, tritium is a suitable tracer for limited portions of the unsaturated zone characterized by short transport times. Also, as discussed in the response to RAI 3.2.2.1.2.1-5-005, the source term for tritium at Yucca Mountain is not well constrained.

In summary, chloride is well-known in scientific literature as a natural aqueous species suitable for quantitative evaluations of infiltration and percolation flux. Chloride is the preferred geochemical constituent for evaluating infiltration and percolation flux because the source term is relatively well constrained and does not participate significantly in chemical reactions in the unsaturated zone environment.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

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NOTE: ^aProvided as an enclosure to letter from Williams to Sulima, dtd 6/5/09, "Yucca Mountain – Request for Additional Information – Volume 3, Chapter 2.2.1.2.1, 5th Set (Scenario Analysis) (Department of Energy's Safety Analysis Report Section 2.2, Table 2.2-5."

5. ENCLOSURES

Enclosure 03 *Tables 2-9.xls*